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MONITORING OF FISH STOCK ABUNDANCE: THE USE OF CATCH AND EFFORT DATA

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

UNITED NATIONS ENVIRONMENT PROGRAMME

MONITORING OF FISH STOCK ABUNDANCE: THE USE OF CATCH AND EFFORT DATA

A report of the ACMRR Working Party on Fishing Effort and Monitoring of Fish Stock Abundance

Rome, Italy, 16–20 December 1975

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THIS PAPER

This paper has been prepared as one element of the cooperative project of the United Nations Environment Programme and the Food and Agriculture Organization on the monitoring of environmental effects on marine world fishery resources. It consists of the report of the first session of a Working Party on Fishing Effort and Monitoring of Fish Stock Abundance established by the Advisory Committee for Marine Resources Research (ACMRR). Attendance at the meeting was supported by the FAO/UNEP project.

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CONTENTS

		Page
I.	GENERAL REPORT	1
1.	INTRODUCTION	1
2.	THE GENERAL PROBLEMS OF CATCH AND EFFORT DATA	1
3.	MEASURES OF FISHING POWER AND FISHING TIME	2
3.1	Towed gears	2
3.2	Encircling gears	6
3.3	Gill-net	8
3.4	Hooks and lines (long-lines, hand-lines, pole and line, troll, jigging	8
3.5	Other gears	9
4.	MULTI-SPECIES PROBLEMS	10
4.1	Time and area resolution	11
5.	SKILL FACTORS AS SOURCES OF BIAS	12
5.1	Common factors	12
5.2	Adjustments to learning bias	13
6.	BIOLOGICAL ASPECTS	14
7.	CONCLUSIONS	14
8.	REFERENCES	15
	Annex 1 - LIST OF BACKGROUND PAPERS	17
	Annex 2 - AGENDA	18
	Annex 3 - LIST OF PARTICIPANTS	19
II.	BACKGROUND PAPERS	21 - 101

I. GENERAL REPORT

1. INTRODUCTION

At its Seventh Session in Rome, October 1973, the ACMRR set up a Working Party on Fishing Effort and Monitoring of Fish Stock Abundance under the chairmanship of Mr. B.B. Parrish with the following terms of reference:

"(i) to identify, by reference to recent specific fishery situations, changes in fishing practices and techniques or in fish abundance or distribution of fish or fishing that can make the catch per unit effort a biased estimator of changes in abundance, and to propose units of effort, and additional information that can reduce this bias;

(ii) to review all methods of regularly monitoring changes in the abundance of commercial fish stocks, and in particular to compare in a general way the relative costs, precision, and risk of bias of different methods. Note should also be taken of the additional information that may be provided by the monitoring procedure, e.g., on size composition, detailed distribution, abundance of pre-recruits, etc.".

Mr. D.J. Garrod, Mr. Ø. Ulltang and Mr. Loh Lee Low were appointed as members of the group. Following correspondence between the Chairman of the Working Party and other scientists, a number of background papers were prepared to help the Working Party in its activities (see Annex 1). The first session of the Working Party was held in Rome, 16-20 December 1975 as part of the Expert Consultation on Monitoring of Fish Stock Abundance, supported by the United Nations Environment Programme. The Agenda of the meeting is given in Annex 2, and the list of participants in Annex 3.

2. THE GENERAL PROBLEMS OF CATCH AND EFFORT DATA

In reviewing the Agenda and terms of reference it was felt that the time available during the first session (which had been cut short because bad weather had delayed the arrival of three of the participants) did not allow full discussion of all the topics. Therefore, rather than attempting discussion of methods other than catch and effort data of monitoring fish abundance, which could not be carried out in much detail, it was felt desirable to postpone discussion of these aspects until a further meeting. Attention was therefore focussed on the first item in the terms of reference. It was recognized that although the uncritical use of commercial catch-per-unit-effort data can give misleading results, and that there are certain fisheries for which the use of these data for abundance monitoring presents great difficulties, for the foreseeable future it is likely that, taking the world as a whole, catch-per-unit-effort data from commercial operations, provided they are properly collected and analysed, will continue to be one of the most important methods of monitoring the abundance of major fish stocks. The Working Party therefore focussed its attention on ways in which bias can arise in the use of c.p.u.e. as an index of relative fish abundance, and of its changes in time for the main types of fishery. Mathematically, it was concerned with examining the degree to which the catchability coefficient q in the relation

$$F = qf \quad ^{1/}$$

$$\text{or abundance} = {}^{1}/_{q} \times \text{c.p.u.e.}$$

may change with time.

1/ F = instantaneous fishing mortality coefficient; q = catchability coefficient; f = effective fishing intensity.

The examination was carried out for each major class of fishery and type of gear. Within each type, consideration was given to the following main sources of possible bias:

(a) features of the fishing unit affecting fishing power; (i) the vessel, (ii) the gear;

(b) the time units used in the effort measures;

(c) the degree to which effort is directed to different species or groups of species;

(d) learning and skill factors.

The magnitude of the effects of each of these possible sources of bias differs according to the type of fishery. For example, the fishing power of a bottom trawl is greatly affected by the size of the net, and the power or size of the vessel that is towing it. The views of the group regarding the importance of each source of bias for each gear type are set out in Table 1. The classifications in the Table are subjective, but are considered to be useful guides as to which elements merit attention in collecting and interpreting effort data for each particular gear. It should be emphasized that the major concern of the group, and of most users of catch-per-unit-effort data, is with monitoring changes in c.p.u.e. from year to year as indices of changes of abundance. Therefore it is changes in the characteristics examined (vessel, gear, fishing time, species preference, or learning) from year to year that are of particular importance.

For example, the fishing power of a trawl is determined by a large number of detailed characteristics of the net and the way it is rigged and used, but so long as these remain unchanged, there is no need to include information on these characteristics in routine fishing effort data. In a long-established fishery, changes may be few, and those that do occur may be striking, e.g., the introduction of Vigneron-Dahl gear into the North Sea trawl fisheries in the 1920's, and require major adjustment to the series of fishing effort data. Others may be more subtle and more gradual and less easily recognized and measured, but they may be equally important as sources of bias over a period of years. In many cases their detection is dependent on a close familiarity of the scientist with fishing gear and fishing practices used. The particular problems relating to source of bias for each type of gear are discussed in detail in the following section.

3. MEASURES OF FISHING POWER AND FISHING TIME

3.1 Towed gears

3.1.1 Danish seine

The fishing power of a Danish seine depends mainly on the size of the gear which, in most Danish seine fisheries, is related to the size of the fishing vessel. Therefore classification of effort measures by vessel size categories will largely take account of this effect of gear size. The time unit for the Danish seine can be either the time the net is actually fishing, or the number of sets. But owing to difficulties in determining the former in each haul (the time between shooting and hauling the gear may be markedly different for consecutive hauls made at different depths and yet the actual fishing time may be the same), the latter is the more appropriate measure. Effort in the Danish seine fishery should therefore be recorded as number of sets by vessel category.

3.1.2 Bottom trawl

The fishing power of a bottom trawl depends on its size and speed through the water. These are usually closely related with the size and/or engine power of the vessels. Many studies have shown a linear relationship between size or engine power of the vessel and its catch rate. Therefore, the collection of effort data by vessel size or engine power category

Table 1

Fishing Effort Components

Type of fishing				Relative Importance[a] of Factors Determining Fishing Effort										
				Gear			Boat			Fishing time (on grounds)		Fish	Fisherman	
Kind of fish	Major target species	Gear	Gear type[b]	Gear Size/ Number	Bait	Gear saturation	Vessel size	Engine power	Fish finding equipment	Actual catching time	Searching time	Changing target species	Skill	Within fleet communication
DEMERSAL	Groundfish	Danish seines	2	+ + +					(+)	+ + + No.of sets			+ (+)	
	Groundfish, shrimp, cephalopods	Bottom trawls	3	+ + +		+	(+)	+	(++)	+ + (+)	(+)	+ +	+	(+)
	Groundfish, crabs	Gillnets, trammelnets	5	+ + +						+ + + No.of sets		+	+	
	Lobsters, crabs, cephalopods	Pots	6	+ + +	(+)					+ + + No.of sets		+		
	Groundfish	Handlines	7	+ +	+	+				+ + +		+		
	Groundfish	Longlines	7	+ + +	+	+				+ + + No.of sets		+	+	
COASTAL PELAGIC	Anchovy, clupeids, mackerel	Purse seines, ringnets	1	+ + (+) (Light)		+ (Vessel capacity saturation)		+	+ (+ +)		+ + +	(+ +)	+ + (+)	+ +
	Anchovy, clupeids, mackerel	Midwater trawls	3	+ +				+ +	+ + +	(+)	+ + (+)	+ (+)	+ +	+ +
	Saury, atka mackerel	Liftnets	4	+ + (Light)		+		+ +	+ + +	(+)	+ + (+)	+ (+)	+ +	+ +
	Clupeids	Driftnets	5	+ + +						+ + (+)	(+)	+	+	+
	Mackerel, various	Troll	7	+ +	+	(+)				+ +	+		(+)	
	Squid	Jigging	7	+ + (Light)						+ +	+			(+)

Table 1 (continued)

Type of Fishery				Relative Importance[a] of Factors Determining Fishing Effort										
				Gear			Boat			Fishing time (on grounds)		Fish	Fisherman	
Kind of fish	Major target species	Gear	Gear type[b]	Gear size/ number	Bait	Gear saturation	Vessel size	Engine power	Fish finding equipment	Actual catching time	Searching time	Changing target species	Skill	Within fleet communication
OCEANIC	Tunas, skipjack	Purse seine	1	+ +				+	+		+ + +	+ (+)	+ + +	+ +
	Salmons	Drift nets	5	+ + +						+ +	+	+	+	+
	Tunas (also for horse mackerel and groundfish)	Traps	6	+ +						+ + +				
	Tunas, skipjack	Pole and line	7	+ +	+ +			+		(+)	+ + (+)	+ (+)	+ +	+ +
	Tunas, billfish	Longline	7	+ + +	+	+				+ + (+) No.of sets	(+)	+ +		+
	Tunas, salmons	Troll	7	+ +	+	(+)				+ +	+			+

a/ graduation = blank: no –; + : little –; + + : fair –; + + + : great importance; ( ) = depending on the fishery considered

b/ gear types: 1 = surrounding nets; 2 = seine nets; 3 = trawls; 4 = liftnets; 5 = gillnets and entangling nets; 6 = traps; 7 = hooks and lines

NOTES ON THE TABLE OF FISHING EFFORT COMPONENTS

This Table attempts to classify and rank the components of effective fishing effort. It does not attempt to identify the possible sources of bias likely to affect the f/F relationship, i.e., the effective effort and the catchability coefficient. Bias results from unsuspected factors, and can often be reduced by obtaining more detailed records of the various aspects of fishing effort: vessel, gear, crew and their activity, and the distribution of fishing relative to the distribution of fish.

In the Table, the fishing effort components with the highest ranks, called primary factors, are those that control fishing effort directly. Components whose effects are indirect, called secondary factors, have lower ranks, even though these factors are often used more in practice because they are often better documented. For example, trawl size is ranked as the primary factor in the fishing power of a trawl fishing unit, but for practical reasons engine power or vessel tonnage are more often taken to measure fishing power. For the same reasons, in most surface tuna fisheries vessel tonnage or hold capacity is chosen as an index of fishing power rather than purse seine length or number of lines; similarly scouting time or time on the fishing grounds is chosen as an index of the amount of fishing rather than the length of track surveyed, which also accounts for differences in vessel speed.

The complexities that result from measuring effort in terms of secondary factors can be avoided by using primary factors; otherwise the confounding of effects inherent in secondary factors must be dealt with. For example, in most cases, if actual fishing time is known, saturation has to be considered only if the gear itself becomes saturated. 1/ But if actual time spent fishing is measured indirectly (e.g., days at sea, number of trips), then effective effort will be influenced by other kinds of saturation (e.g., those that occur in handling the catch on board). In a handline fishery where fishing time is measured indirectly as the number or duration of trips rather than directly as gear soaking time, estimated fishing effort will have to be adjusted for changes in fishing grounds and in vessel speed, which will modify the ratio of soaking time to time at sea.

Obviously, some of the identified components of fishing effort mainly depend on the gear-boat-crew unit, while others depend on the characteristics of the fished stock (areal distribution, schooling, vertical movements, etc.). But these two kinds of components are not wholly separable. The skill of the fishermen, for instance, depends in part on their ability to manoeuvre the boat and the gear, and in part on their ability to locate higher concentrations of fish.

1/ In a purse seine fishery, hold saturation also occurs when a single set captures fish in excess of vessel capacity.

will eliminate the need for information on gear size and other characteristics correlated with size or power category. Knowledge of the characteristics of a fishery is required to determine whether vessel size or engine power or a combination of both is the better criteria for classification. This depends on, for example, the possibility of obtaining meaningful data on engine power, on the use of the available engine power during fishing, and on the relation between vessel size and engine power. Different types of bottom trawl (e.g., single boat otter side trawl, stern trawl, pair trawl, beam trawl, single or double rig, shrimp trawl, etc.), distinguished in international gear classifications, have different fishing powers and should be kept separate in the data collection.

In several bottom trawl fisheries searching is of minor importance. In such fisheries, the total time of actual fishing (towing time), per size or power category of the vessels, gives the best effort estimate, although number of days fishing will give a reasonable approximation. Other approximation, e.g., total number of days on the grounds, or days absence from port, are useful if more detailed data are unavailable, but in such cases it would be necessary to make corrections for time required for steaming, for loss of fishing time due to weather conditions, etc.

If, however, searching plays a more substantial role, total number of days spent fishing is likely to give a more appropriate measure than total towing time. If possible, information on actual fishing time and time spent searching should be collected for more detailed studies of changes in the fishing operations and hence in the importance of searching as a component of the effort unit.

The decision on which measure of fishing time to use, e.g., number of trips, days at sea, days in the fishing grounds, days fishing (i.e., the number of days on which fishing took place), number of hauls or hours with the net actually on the bottom, should, in principle, be best taken after the reasons for any changes in the ratio of these different measures have been ascertained. If there are no changes, the use of different measures will change only the scale of the c.p.u.e. and not its validity as an index of abundance. In the early 1950s English distant water trawlers did less trawling (hours fishing with the net on the bottom) per day on high fish densities because they had to stop to handle the accumulation of fish on deck. In this situation hours fishing is clearly better. On the other hand, nowadays many trawlers, especially those with good fish-finding equipment do less fishing per day at low levels of fish abundance because they spend more time looking for concentrations of fish worth setting their net on. Here days fishing is better.

3.1.3 Midwater trawl

In midwater trawling, engine power is the key factor determining the size of net used, and the speed of towing, and hence the fishing power of the vessel. Fishing effort data should therefore be collected by vessel engine power categories. Since in almost all midwater trawl fisheries, searching (with echo-sounders or sonor) forms an important component of the individual fishing operations, the time actually spent fishing is an inadequate measure of effort. Its use alone may give rise to serious bias. Days fishing is likely to be a more satisfactory measure for midwater trawl fisheries, but it is very desirable to also collect detailed data on searching time and actual fishing time (if necessary on a sampling basis) so that comparison can be made of the various estimates and eventual later correction of the catch per day fishing data. Searching time can eventually be determined from information on the number of days fishing, and the actual towing time.

3.2 Encircling gears

The encircling gears such as purse-seine and ring net are usually directed towards schooling fish species and they must be used by aimed fishing. Catch-per-unit-effort is therefore strongly influenced by the skill of the fishermen (in detecting the fish school and in gear handling) and the behaviour of the fish as well as by the technological characteristics of the fishing unit.

Amongst the technological characteristics the size of vessel, its gear and its engine power may all be equally important in particular fisheries. For example, the power of the engine may influence the speed and hence success of a set within a vessel size category so it may be necessary to combine several parameters to arrive at an appropriate fishing power index.

Many encircling fisheries are based on low-value, large quantity species, e.g., anchovy or sardine, and are particularly susceptible to saturation of the handling and carrying capacity of the vessel so that the unit of time chosen in calculating effort should be small enough to exclude this effect, i.e., c.p.u.e. should be calculated as catch per shot, or catch per hour on the fishing grounds, rather than catch per day on the fishing ground or per trip. Alternatively, provision must be made to identify periods when saturation rather than fish abundance has limited the catch. The same effect may also be reflected in high discard rates and these also should be recorded in order to avoid underestimation of the catch per unit effort.

The reliability of c.p.u.e. as an index of changes in abundance in these fisheries is very sensitive to the way in which the distribution, shoaling characteristics and density change with changes in total abundance. Decreased abundance may be reflected in one or a combination of smaller average school size, a greater distance between schools, or a reduction of the total area inhabited by the exploited stock.

Changes in school size will probably be reflected in proportional changes in catches per shot (especially when any successful set catches an entire shoal), in which case most measures of c.p.u.e. will provide reliable indices of abundance.

A change in the distance between schools places a premium on search capability and efficiency, both of which may be expected to improve over time as a result of technical developments (e.g., in fish detection instruments) as distinct from increases in fishing power alone. This is especially true if associated with improved communication and search strategy by fleets operating as a unit and by the tendency for fishermen to set their nets with greater care when fish are scarce. Search time must therefore be incorporated in the time component of the effort unit. Where fishing trips extend over several days, searching time may best be incorporated by including all fishing-related activities in the fishing effort unit, i.e., days on the fishing grounds or days in which fishing took place may be appropriate time units. On the other hand, where trips are of short duration, it may be necessary to use a more precise measure of the time (hours) spent on fishing-related activities.

A reduction in the area occupied by the fish stock implies that the fish stock tends to maintain the same general density level in the area occupied, and that changes in total abundance are reflected in changes in the size of the stock area. Catch-per-unit-effort estimates unadjusted for such changes will therefore only be an index of local shoal density or shoal size and may give very biased measures of changes in total abundance over time. This effect may be corrected by a proper knowledge of the area distribution used as a weighting index. This may be available from the time/area resolution of the statistics collection and reporting system, but because of their search techniques the coverage of a commercial fleet may be inadequate. If this is so then the commercial data must be augmented from other sources - e.g., acoustic and fishing surveys by research vessels.

In general these various sources of bias will tend to minimize population changes estimated by catch-per-unit-effort data for encircling gear fisheries. They are similar but more extreme than the bias identified for other fisheries and no completely satisfactory method has yet been found to correct for all of them. In a purse seine fishery then, more than any other fishery, the choice of effort units for estimating catch-per-unit-effort must be made very carefully, and the data interpreted with great caution and, wherever possible, corroborated with independent sources of information.

3.3 Gill-net

The most important power factor is the size of gear, which may be measured as number of nets. Number of nets x days fished will probably give an appropriate measure of effort in most fisheries. Care should, however, be taken to watch for significant changes in the fishing gear, e.g., in size of nets, the materials in which they are made, the way they are rigged, or the average duration for which they are fished. If so, the possible effect of these changes on fishing effort should be checked, and adjustments made if necessary to the measures used. Searching time may be an important factor in drift, gill-net fisheries aimed for schooling species, but not in bottom gill-net fisheries. Change in target species will not be a major problem in drift gill-net fisheries, except in some salmon fisheries where effort may be directed towards different types of salmon. In bottom gill-net fisheries the mixture of species in catch may create problems in estimating the effort directed towards a special species.

3.4 Hooks and lines (long-lines, hand-lines, pole and line, troll, jigging)

In most bottom and pelagic long-line fisheries the fishing power in hook and line fishing is mostly governed by the number of hooks operated during a fishing operation, though for convenience they are often recorded in units (e.g., baskets or "skates") which usually have a standard length and a standard number of hooks. In some other kinds of line fisheries on the other hand only a small number of hooks can be efficiently operated simultaneously from the same boat. For example, in the albacore troll fishery in the Bay of Biscay, boats are all rigged in the same way with the same number of lines. In such fisheries, therefore, fishing power may be expressed simply as the number of fishing units in operation, where necessary divided into vessel (or crew) size categories. It is necessary in using such a measure to make detailed, periodic surveys to check whether significant changes have taken place in boat/gear/crew characteristics, in gear design and rigging or in fishing practices. Changes in rigging may be particularly important in affecting catching efficiency. For example, Skud (1972) has shown that an increase in the number of hooks per unit length increased the catch of small Pacific halibut, but not that of larger halibut.

Bait - natural and artificial - is used in most kinds of line fishing, except jigging. The extent to which its nature (species, size, material for artificial lures) affects fish catchability varies with different fisheries. Information on bait has to be regularly collected and experimental fishing should be conducted from time to time with the purpose of comparing effectiveness of various kinds of bait. In pole and line fishing, limited bait supply may significantly reduce the amount of the total time at sea a boat can devote to tuna fishing. The resulting possible bias would be obviated if time spent for searching and capturing tuna is recorded separately from the time devoted to bait fishing and other non-directly productive time components.

Gear saturation effects are likely to occur in almost all kinds of line fishing; relevant information should therefore be regularly collected on these parameters and incorporated in the calculation of effort and abundance indices.

In most bottom-line fisheries, acoustic instruments are mainly used for better location of fishing grounds (through observations of bottom topography), and seldom for the direct detection of fish concentrations. Fisheries with lines for small pelagic fish species are mostly of a small-scale nature, in which the use of electronic equipment is limited. In pelagic tuna fishing, school detection is mainly made through the observation of associated fauna (flocks of birds, porpoises, etc.) and the impact of such equipment on fishing efficiency is therefore likely to remain limited.

As for most other fishing methods, the respective roles of searching time and of time actually spent during catching operations depend more on the variability in stock distribution than on the gear used itself. In this respect searching time would be essential

and would therefore have to be recorded as such in most surface tuna fisheries (e.g., pole and line), whereas its importance in handlining for groundfish would usually be negligible. Pole and line represents an extreme case in which trip duration has to be properly allocated according to its four major components: steaming between port and fishing grounds and other dead times, fishing for bait, searching for suitable tuna schools and finally catching. However, the respective impact of searching and of capturing times may appear difficult to integrate when deriving effort estimates; their separate recording may also raise practical difficulties. But even when only total time on the fishing grounds can be used, possible significant long-term changes in these two basic components must be properly monitored and accounted for to avoid biased results.

In some small-scale inshore line fisheries fishing operations and trips are often of constant duration, e.g., when they are adjusted to the tidal cycle. Similarly, in tuna longlining soaking time remains more or less constant for each set. Measurement of fishing time can then be made by simply recording the number sets, or in some cases the number of trips. But, again, periodic checks should be made of changes in fishing practices which affect fishing efficiency.

Based on the above factors, fishing effort for the various types of line fishing would be best measured in the following units:

- handlines/groundfish	: Number of lines, soaking time (or trips)
- longlines/groundfish, tuna	: Number of hooks, number of sets
- troll/tuna, salmon, small pelagic	: Time on fishing grounds, adjusted for number of lines
- jigging/squid	: Number of nights, adjusted for number of gear units
- pole and line/tuna	: Searching time and time on tuna fishing grounds, adjusted for number of hooks with, according to the particular fishery, additional adjustments for differences in bait, rigging, searching, number of gear units, etc.

Other adjustments would be required for changes in target species in all fisheries (in pole and line and long-line for tuna mainly) which are exerted on a relatively small number of species, the respective commercial value of which is likely to fluctuate with time. Skill may raise special problems, in pole and line fishing for instance where its role is important. Changes in the pattern of communication within a given fleet could generate bias, particularly in fisheries such as those with pole and line where fish concentrations are not easy to locate. Such possible bias would be reduced by finer time/space resolution in catch data collection.

3.5 Other gears

3.5.1 Light fishing

The use of light for attracting fish, e.g., in some purse-seine, lift-net and jigging fisheries brings a particular set of factors to the measurement of catch-per-unit-effort. In such fisheries, the fishing effort is directly related to the attractive power of the light source (intensity, wave length, immersed or not, etc.), the characteristics of the catching gear and to the number of nights fished. As the attractive efficiency of artificial light is affected by moonlight, lunar phases - and possibly seasonal changes in cloud coverage - have to be accounted for, particularly when processing the raw data. It could be noted here that the same need may occur in other types of fishing in which efficiency during night operations is influenced by moonlight, even when no artificial light is used (e.g., in purse-seining where fish is detected through the observation of surface bioluminescence).

Sometimes searching is carried out during day time before initiating attraction of fish (e.g., in purse-seining with light). Effects of searching on the fishing effort estimates could often be accounted for by refined time/space resolution in data collection; otherwise catches would have to be referred to each 24 hour period each vessel spends at sea.

3.5.2 Lift nets

The main sources of bias in lift-net fisheries are to be expected from incorrect estimation of fishing time and from improper allocation between searching time and time actually spent fishing. The fishing power is relatively less affected by vessel characteristics, though account should be taken of the number of gears which can be simultaneously operated from a single boat (i.e., to express c.p.u.e. as catch per net, not catch per boat). Searching efficiency can be significant in determining fishing power.

3.5.3 Pots

The main fishing power component in pot fisheries is the number of pots set, and effort should be recorded accordingly. Boat characteristics do not affect directly fishing power, but only indirectly through the number of pots carried per trip. More precise estimates would be generated if the kinds of pots and bait used are accounted for.

3.5.4 Fixed traps

These are probably the fishing gears for which sources of bias are the smallest - at least for a given unit of gear no influence of operating crew or boat is to be expected. However, changes in catching capacity are to be expected according to its size and possibly also from the way the net is mounted and set. However, these gears and some of the passive ones (pots, gill-nets, lines, etc.) do depend on the appropriate behaviour of the animals. This behaviour may be affected by changes in density, e.g., due to crowding, or in the local environment. For example, coastal traps may be less effective if the waters become polluted.

4. MULTI-SPECIES PROBLEMS

Any fishing gear is capable of catching a variety of species, each of which has a different distribution in space and time, has a different behaviour, and may well attract a different price on the market. The catch of a given species taken by a unit of effort by a particular gear will be determined, often to a large extent on where and when a fisherman chooses to fish in relation to the distribution of that species, and how he operates his gear. His choice will be mainly determined by the abundance of the species and its market price, both of which may change. Thus, where more than one species is caught in a fishery, the c.p.u.e. of any one species may not be a reliable measure of the abundance of that species, because of changes in species preference. In general changes in the relative c.p.u.e. of different species will exaggerate the real changes in relative abundance so that, for example, the decline in a species that has been the prime objective of a fishery will tend to be over-estimated as the fleet moves to other species.

Two simple cases occur - when a species dominates the catches, so that fishing is always directed to maximizing the catch of that species (e.g., anchoveta in Peru), or when a species is so unimportant that it could never be a factor in determining the fisherman's tactics (e.g., brill or gurnards in the North Sea). There are two dangers in the latter - first that the species concerned has a similar distribution or behaviour to other species of more importance, so that changes in the fishermen's preference for the more important species could affect the c.p.u.e. of the less important one, e.g., catches of brill would be increased by fishermen adjusting their gears to catch more plaice or other flatfish. Secondly, less preferred species may be discarded when catches are generally good so that while the catches of gurnard per unit effort may not be affected by fishing practices, the landings per unit effort may well be.

Often, however, several species are potentially important targets for the fishermen's attention, and the interpretation of c.p.u.e. data of any given species depends on some knowledge of the degree to which it has been the major target. This is most easily obtained on a post facto basis, using the percentage composition in the catch. Given such information it is possible to treat any haul or trip containing more than a certain percentage of a particular species as having been directed towards that species (e.g., Ketchen, 1964). The catch and effort data of these hauls or trips are then used in computing the c.p.u.e. for it. This procedure may, however, introduce biased indices of abundance and in particular may underestimate the decrease in the abundance of a species which is declining through time, since only the successful hauls or trips may be included in the c.p.u.e. estimate. It is impossible to tell from the catches how often a fisherman went looking for a particular species, and after some failures was satisfied with catching some other species. At least partial correction of this source of bias can be made if the overall intention of the skipper per trip or season is known (this information is sought in the statistical reporting system of ICNAF). In practice, however, this information is difficult to acquire in an overall statistics collection and reporting system since the target species may vary from haul to haul according to circumstances with the result that the skipper's intent is reported as mixed species. Similar problems may arise when the target is not a particular species, but special size categories of a species.

4.1 Time and area resolution

Use of detailed information on catch and effort on a time and area breakdown can help to deal with the mixed species problem, at least when changes in species preference cause shifts in fishing ground greater than the resolution of the statistical system used. For example, in the Japanese long-line fishery for tuna, shifts from the largely tropical yellowfin tuna to the largely sub-tropical and temperate albacore involve changes over distances much greater than the 5° squares used in reporting statistics, and suitable adjustments can therefore be made.

Time and area details can also be useful in single species situations, particularly when there may be a change in the area inhabited by the stock as the total abundance decreases (as discussed above under encircling gears), or when a fishery exploits only part of a resource. In the latter case the fishery may extend its area of operation as the local abundance is decreased by fishing, thus maintaining its c.p.u.e. and masking any effect of fishery.

The detail of the time and area breakdown used in the collection of the catch and effort data has to be decided carefully. Clearly the finer the breakdown in time and area the better the chances that the information can produce unbiased indices of abundance. Equally clearly, additional detail adds to the burden of collecting and processing the data, and can result in a volume of information that is difficult to digest - though the use of computers to produce graphic presentations of extensive catch and effort data (Loh Lee Low, 1974) can resolve the latter difficulty.

The work involved in the original collection of the catch and effort statistics increases very much when there is a change from recording each individual trip (by records or interviews made at the end of each trip), to recording each haul which will usually require that a special log-book is completed for each vessel engaged in a fishery, or a representative sample of them. Otherwise the degree of detail required does not affect the work very much; it does not take much more time to record the fishing position for one trip to within a half degree square, than say to a broad area such as the North Sea. It is therefore desirable to collect the data in as much detail as possible, at least as regards the initial recording. Analysis may show how much detail in final tabulations is needed at any time, and routine compilations may for convenience be restricted to this detail.

In the open seas it is usually most convenient to use an area grid system, and where possible each stage of detail should be compatible with finer or coarser groupings, e.g.,

by using lines of latitude and longitude at, say, intervals of 10°, 5°, 1° or less. Grouping of areas together can then be easily made. If necessary, modifications to a rectalinear system can be made to conform with major features of the coastline, bottom topography, etc., particularly those that may reflect important divisions between fish stocks, ecological systems, etc. In particular, a breakdown by depth zones may be desirable, particularly for demersal species.

5. SKILL FACTORS AS SOURCES OF BIAS

During the development of any fishery, there is usually a certain amount of "learning" associated with fishing techniques and operations. Over periods of time, such changing skills may alter effective fishing effort and hence bias c.p.u.e. estimates towards overestimating abundance in the more recent years. There are commonly three situations with different risks of bias:

(a) the initial stages of a fishery, when the learning process can be very rapid and important;

(b) well-developed fishery, in which the learning process essentially slows down and the level of skill does not change significantly for a period of time. Learning by new entrants to the fishery will be balanced by retirement of some of the more experienced fishermen;

(c) a stage of declining fish stock abundance and catch rates, when the fishing fleet has to find improved or new fishing methods to maintain its catches. These introductions lead to increased fishing efficiency and hence to a certain amount of bias in the catch-per-unit-effort estimates, used as indices of abundance.

5.1 Common factors

In general, changing skill or learning effects have been distinguished as human-related factors as opposed to technological changes of the fishing gear. The latter changes can usually be calibrated and data necessary to reduce for their bias have been identified in earlier sections. However, in the case of changing skills, the calibration of such effects can be quite subjective.

Among the important factors associated with changing skills of fishermen, the Working Party identified skills associated with:

(a) Technique in locating fish: such as use of echosounders which can add substantially to the effective fishing power of vessels. The technique of locating fish can change q substantially, especially when acoustic devices are used during the stage of declining stock abundance. They are indispensable in midwater trawling operations. Detailed study of sample data on presence, type and use of acoustic instruments at regular (e.g., yearly) intervals would be of great value in the interpretation of c.p.u.e. data, even though it is often difficult to quantify the effect of the various types of these instruments and their use. Where possible, comparative fishing experiments would enable estimates to be obtained of these effects, and to adjust the c.p.u.e. data accordingly. Similar considerations apply to other methods of fish detection (e.g., use of aeroplanes) and catch monitoring (e.g., use of net sonde).

(b) Technique in fishing: such skills in fishing are difficult to quantify. Incentive and experience are important considerations. Distinct differences are often identified by group of fishermen or fishing fleets. Data by vessel size, gear type, and national origin usually collected to reduce bias due to other technical factors may also serve to reduce bias due to fishing skill. Where distinct levels of skill are evident, sample surveys ought to be collected to adjust for c.p.u.e. bias accordingly.

(c) Use of communication devices: which is very important in the developmental stages and again in declining stock abundance stages of the fishery. The organization of the fleet and degree of cooperation between vessels are key factors. As in the case of fishing skills, bias due to communications are difficult to adjust for and grouping of data to reduce bias due to technical factors may be sufficient.

5.2 Adjustments to learning bias

The Working Party recognized that such sources of bias are important considerations, but was unable to propose a single, effective method for correcting it. Much of it is subjective. The bias may arise in a uniform progressive way with time, as is likely to be the case during the early stages of development of a fishery, or it may arise step-wise, as a result of a technological change. The learning curve normally reaches a plateau and changes abruptly again when something drastic happens to the fishery, whether by regulation or over-fishing.

There are three approaches that may be used to estimate learning bias:

(a) Relate commercial c.p.u.e. trends to independent survey: stock size can be estimated independently by acoustic or other survey techniques and such trends may be related to commercial trends. An example, given by Brown et al., (1975), did not attempt to define the learning factors in terms of explicit causes, but instead approached the problem by assuming that it would be expressed as a consistent increase in c.p.u.e. through time that is not related to changes in stock abundance. An exponential learning model is assumed to be:

$$\left(\frac{X_i}{Y_i}\right)\left(\frac{Y_1}{X_1}\right) = \left[\exp(a(i-1))\right]e_i, \text{ where}$$

X_i = the observed commercial c.p.u.e. in the i^{th} year in the fishery after entrance;

Y_i = the stock abundance in the same year as determined by an independent survey; and

e_i = residual error, where $\ln(e_i)$ has a $N(0, \sigma^2)$ distribution.

The parameter, a, is then estimated to define the learning curve for adjusting fishing effort levels.

(b) Monitor and evaluate fishing results of newcomers as opposed to those of established fishing vessels: Comparison of such individual records can shed some light as to the pace and range of learning. However, this approach is not completely satisfactory in that the newcomer has examples to follow, whereas the earlier fishermen did not.

(c) Evaluate historical records of individual vessels and skippers: The skill of skippers, their crew and the vessels in general can be weighted in a census and then related to historical records of such vessels in the sample.

The effect of changing skills or learning as a biasing factor in the use of c.p.u.e. data to determine changes in stock abundance with time is considered by the Working Party to be extremely important in many fisheries, and it stresses the need for detailed studies of this subject. Such types of data need not be collected routinely in catch-effort statistics but should be collected periodically by survey and certainly when major changes take place, such as mass installation of echosounders.

6. BIOLOGICAL ASPECTS

The usual output from catch and effort data, and the immediate analyses of this output (e.g., in the Schaefer or production models) treats the fish population as though it can be described by a single number (e.g., biomass, or numbers caught per unit-effort). This is seldom entirely valid. The Working Party emphasized that additional biological information will usually be needed in comprehensive analyses of fish stocks, but within its terms of reference concentrated on those items of information that may be needed before figures of c.p.u.e. can be reliably used.

One aspect is that of the distinction between statistics of landings (which are the data most commonly available), and the actual catches. Discarding of small or less valuable fish occurs in many fisheries, and the proportion discarded is likely to decrease when the stock abundance decreases; that is fishermen keep more fish and the landings per unit effort will change less than the abundance. Data on discards should be routinely collected, wherever discarding is significant, so that catches and hence catch-per-unit-effort can be directly calculated. Failing that, data on the characteristics of the catches, especially size, should be collected, so that changes in, for example, size composition can provide evidence of changes in discard practices. While size is likely to be the most common important factor, in some fisheries other factors can be important. For example, in some fisheries the main product is the roe, and the fishermen may only land pre-spawning females. A change in practice to landing all fish could lead to a big increase in the recorded catch-per-unit-effort.

Changes in fishing practice are not restricted to discarding. By changing their attention between different sizes, e.g., towards smaller, less valuable but more abundant size-classes, fishermen can change the catch-per-unit-effort even though the stock abundance is unaltered. The sizes of fish caught (and ages where this can be determined, and possibly other factors, e.g., maturity) should therefore be always monitored to detect such changes.

The other group of biological characteristics for which data are needed in order to interpret catch and effort data is movement, migration and stock structure. In particular it is highly desirable to know the degree to which the catch and effort data covers the whole distribution of the stock (for the whole year, or for some particular season). If only part of the stock is available, changes in the observed catch-per-unit-effort may reflect only changes in that part of the stock, and be poor indices of changes of the total abundance. In particular, in a decreasing stock, the decrease in the fringe of the distribution may be much greater than that at the centre.

7. CONCLUSIONS

The previous sections have discussed many sources of possible bias in c.p.u.e. and outlined ways in which these might be overcome. Some sources, e.g., changes in average size of bottom trawlers, can usually be dealt with easily and in a quantitative manner, whereas others, e.g., changes in searching efficiency and fishing skill are less easy to detect or to measure. For those fisheries in which quantitative adjustments can be made for any major changes in the effectiveness of a nominal unit of effort that may occur, catch-per-unit-effort data provide reliable indices of changes in abundance. This does, however, require that the scientists using and interpreting the data have a close familiarity with the fishery, so that they will become quickly aware of any changes in vessel, gear, or the general fishery techniques that might affect the units of effort, and make appropriate adjustments.

However, in many fisheries it is very difficult to be sure that proper account has been taken of all the changes in effectiveness. However, even if this is the case, the direction of most changes will be known. For example, changes in the equipment or techniques of fishing will usually lead to increased effectiveness with time, so that c.p.u.e. in the years after the changes will over-estimate abundance, relative to that in

earlier years, and hence underestimate the change in abundance with time. Similarly, a reduction of the area of distribution with decrease in abundance, or gear or vessel saturation at high fish densities, will result in measures of c.p.u.e. which will underestimate changes in abundance. Conversely, where changes in target species occur, the c.p.u.e. data are likely to overestimate the changes in relative abundance of different species. If the direction of bias in a fishery is known, then even if the magnitude is not measurable, useful conclusions may still be reached, provided the existence of the bias is taken into account.

For some fisheries, notably those with purse-seines or similar gear, on schooling pelagic species, bias is so probable and likely to be so significant that c.p.u.e. data cannot be used, or only with great caution. For these fisheries other independent methods of monitoring abundance changes are necessary. Indeed, these methods - e.g., fishing or acoustic surveys, egg and larval surveys, or (where age-data of commercial catches are available) cohort analysis - are highly desirable in providing independent checks on the reliability of c.p.u.e. data. These methods will be considered in more detail in the future activities of the Working Party.

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Annex 1

LIST OF BACKGROUND PAPERS SUBMITTED TO THE WORKING PARTY

Chikuni, S. : Problems in monitoring abundance in the multi-species and multi-gear groundfish fisheries in the Bering Sea. 14 p.

Garrod, D.J. : Catch per unit effort in long-range north Atlantic demersal fisheries, and its use in conjunction with cohort analysis. 14 p.

Jones, R. : The catch per unit effort of North Sea haddock, whiting and cod as an index of stock abundance. 11 p.

Levi, D. : Fuel consumption as an index of fishing effort for small and medium range trawl fisheries, with particular reference to the Mediterranean trawl fisheries. 6 p.

Low, Loh Lee : Derivation of catch per unit of effort from commercial fishing statistics for the Bering Sea, 1964-73. 16 p.

Miyake, P.M. : Data requirements for obtaining less biased catch per unit effort for Atlantic tunas. 6 p.

Ulltang, Ø. : Catch per unit effort in the Norwegian purse seine fishery for Atlanto-Scandian (Norwegian spring spawning) herring. 11 p.

Annex 2

AGENDA

1. Opening of the Session and Adoption of the Agenda

2. Identification of Sources of Bias in Annual Series of Effort or C.P.U.E. Data

   2.1 Vessel (e.g., size, horse-power, etc.)

   2.2 Fishing gear (e.g., size of net)

   2.3 Other equipment (e.g., sonar, fish pumps, etc.)

   2.4 Fishing time (e.g., increasing hours fishery per trip)

   2.5 Searching

   2.6 Learning

   2.7 Species preferences

   2.8 Others

3. Standardization and Estimation of Correction Factors

   3.1 Feasibility and methods of estimating correction factors

   3.2 Review of data on correction factors, e.g., relation of fishing power to tonnage or horse-power

   3.3 Recommendations for units and reporting procedures

4. Other Methods of Monitoring Abundance

   4.1 Absolute abundance

   4.2 Relative abundance

5. Biological Data

6. Future Activities of the Working Party

7. Preparation of the Report

Annex 3

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II. BACKGROUND PAPERS

	Pages
PROBLEMS IN MONITORING ABUNDANCE IN THE MULTI-SPECIES AND MULTI-GEAR GROUNDFISH FISHERIES IN THE BERING SEA, by S. Chikini	23-36
CATCH PER UNIT EFFORT IN LONG RANGE NORTH ATLANTIC DEMERSAL FISHERIES, AND ITS USE IN CONJUNCTION WITH COHORT ANALYSIS, by D.J. Garrod	37-50
THE CATCH PER UNIT EFFORT OF NORTH SEA HADDOCK, WHITING AND COD AS AN INDEX OF STOCK ABUNDANCE, by R. Jones	51-61
FUEL CONSUMPTION AS AN INDEX OF FISHING EFFORT FOR SMALL AND MEDIUM RANGE TRAWL FISHERIES, WITH PARTICULAR REFERENCE TO THE MEDITERRANEAN TRAWL FISHERIES, by D. Levi	63-68
DERIVATION OF CATCH PER UNIT OF EFFORT FROM COMMERCIAL FISHING STATISTICS FOR THE BERING SEA, 1964-73, by Loh Lee Low	69-84
DATA REQUIREMENTS FOR OBTAINING LESS BIASED CATCH PER UNIT EFFORT FOR ATLANTIC TUNAS, by P.M. Miyake	85-90
CATCH PER UNIT OF EFFORT IN THE NORWEGIAN PURSE SEINE FISHERY FOR ATLANTO-SCANDIAN (NORWEGIAN SPRING SPAWNING) HERRING, by Ø. Ulltang	91-101

PROBLEMS IN MONITORING ABUNDANCE IN THE MULTI-SPECIES AND MULTI-GEAR GROUNDFISH FISHERIES IN THE BERING SEA

by

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CONTENTS

		Page
1.	INTRODUCTION	24
2.	POLLOCK FISHERY	24
	2.1 Selection of catch statistics by type of fishery	24
	2.2 Annual change in fishing efficiency	27
3.	PACIFIC OCEAN PERCH FISHERY	27
	3.1 Difference in fishing efficiency with vessel size	27
	3.2 The bias of apparent CPUE	30
4.	DISCUSSION	35
	4.1 Evaluation of effective fishing effort	35
	4.2 Fishing gear, vessel size, and fishing efficiency	35
	4.3 Coverage of the area	36
5.	REFERENCES	36

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1. INTRODUCTION

There are more than ten species which have been exploited by the groundfish fishery in the Bering Sea. They are pollock, Pacific ocean perch, black cod, Pacific cod, yellow-fin sole, turbot, Greenland halibut, rock sole, flathead sole, halibut, herring, and shrimps. Some of them are taken as the target species and the others as the by-catch species. Six kinds of gear have been used for the fishery including pair trawl, Danish seine, side trawl, stern trawl, longline, and gill-net. The groundfish fishery can be divided into two parts, the mothership fishery and the independent vessel fishery. Monitoring stock abundance in the Bering Sea is very difficult because stock utilization in the Bering Sea is very much complicated by the multi-species and multi-gear character of the fishery.

In this report, the author introduces two examples of the procedure to monitor the abundance of specific stocks in the Bering Sea recently developed by Japanese scientists, and discusses the general problems involved in the procedure in the course of presenting the two examples.

2. POLLOCK FISHERY

Pollock in the eastern Bering Sea occur mostly on the continental slope in the south-eastern part in winter and spring, and move to the continental shelf and migrate on the shelf in summer and autumn. It was in 1962 that the pollock stock began to be utilized substantially (Table 1). Although the annual catch increased gradually thereafter, the fishery did not actively seek to catch pollock until 1967 because pollock was only used for fishmeal along with flounders and other species. With the innovation of producing frozen mince-meat aboard vessels in 1967, the directed fishing for pollock began, and the annual catch has been increased markedly since then (Table 1).

There have been two types of operation since 1967 in both the mothership and the independent vessel fisheries. In one, the vessel is equipped with both mince-meat and freezing plant and depends mostly on pollock; in the other, it is equipped with freezing plant only and catches a variety of species including pollock.

Pollock has been taken by four kinds of fishing gear. Pair trawls achieved the greatest catch through the years (Table 2). When fish of a species are caught by more than one gear, it is necessary to select a standard fishing gear because the fishing efficiency is different among fishing gears. The pair trawl is considered to be the most appropriate gear for the purpose.

2.1 Selection of catch statistics by type of fishery

The two types of fishery operation described above have been conducted in the Bering Sea since 1967. Classification of these two can be made according to whether or not the mothership or independent vessel was equipped with a mince-meat plant. The statistics for pair trawlers, which were selected as the standard gear, were divided according to this classification.

For years prior to 1967 this division cannot be done because there was no mince-meat plant yet on any vessel. Therefore, the daily catch records of pair trawlers in which the catch of pollock was in the first rank were selected to make up the statistics for the pollock fishery prior to 1967. The statistics from these selected data can be regarded as the results of fishing operations directed mainly to pollock.

The catch per unit effort (one hour of hauling) of a pair trawl calculated from the selected statistics (CPUE$'$) is shown in Fig.1, along with the catch per unit effort calculated from the statistics for all pair trawling (CPUE). The CPUE$'$ is larger than the CPUE as it is natural from the data selection procedure. In other words, the catch per unit effort should be under-estimated unless the catch statistics are selected carefully taking the type of fishery into account.

Table 1

Catch of pollock in thousands of metric tons for the Japanese fishery in the Bering Sea during 1960–1972

Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Catch	26	24	60	114	180	235	271	643	676	874	1 271	1 512	1 645

Table 2

Catch of pollock in thousands of metric tons by fishing gear for the Japanese trawl fishery in the eastern Bering Sea

Year	Pair trawl	Danish seine	Side trawl	Stern trawl	Total
1964	33.8	138.5	2.5	0.5	175.3
1965	44.3	176.5	5.6	1.4	227.8
1966	60.9	129.5	66.6	7.0	264.0
1967	137.5	254.0	51.3	103.5	546.3
1968	167.6	326.3	11.4	161.8	667.1
1969	154.0	353.1	14.8	319.0	840.9
1970	367.8	445.6	4.6	384.9	1 202.9
1971	485.6	362.4	-	643.1	1 491.1
1972	636.0	313.0	-	700.2	1 649.2

Table 3

Annual change in vessel number by size-class, average tonnage, and average power of engine of pair trawl for the Japanese pollock fishery in the eastern Bering Sea

Year	Size-class in gross tonnage -100	-150	-200	-250	Total	Average tonnage (ton)	Average power of engine (PS)
1965	6	10	-	-	16	106.3	360
1966	10	10	-	-	20	103.0	405
1967	4	20	4	-	28	117.9	431
1968	4	12	10	-	26	135.4	575
1969	2	10	6	-	18	132.2	733
1970	2	6	20	-	28	160.7	787
1971	-	4	34	-	38	176.6	943
1972	-	4	38	6	48	183.3	978

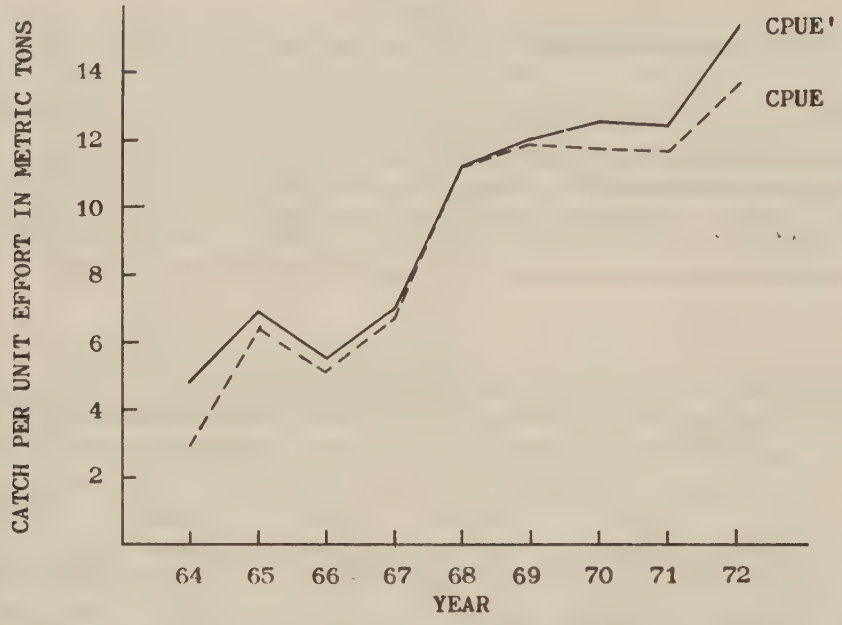

Fig.1 Difference in the two kinds of catch per unit effor of pollock for the pair trawl of the Japanese fishery operated in the eastern Bering Sea, CPUE' obtained from the selected catch statistics for pollock fishery and CPUE calculated from the statistics for all fisheries combined.

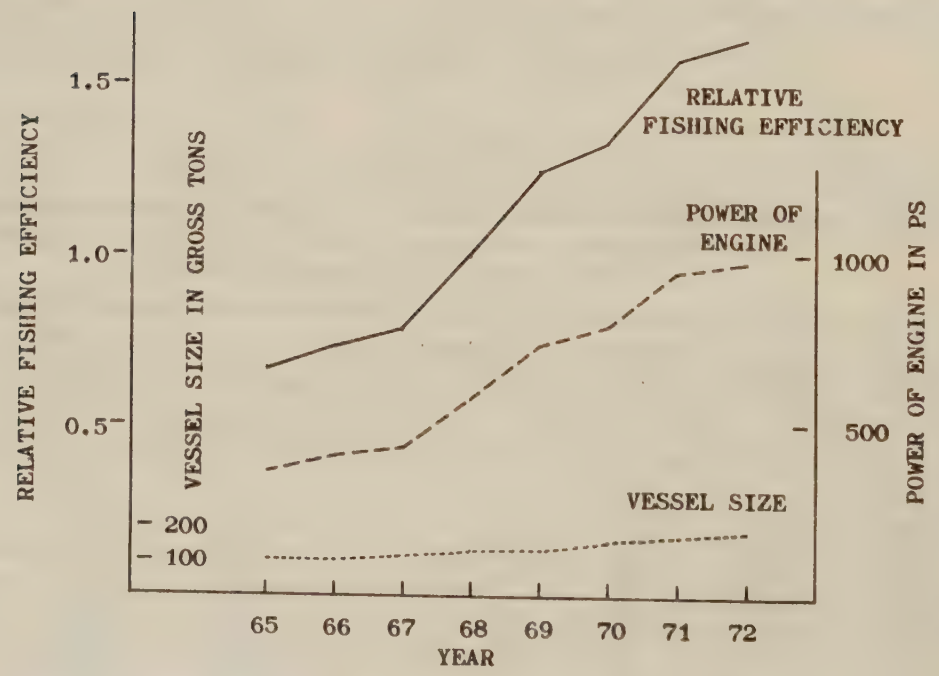

Fig.2 Annual changes in vessel size, power of engine, and relative fishing efficiency for pair trawl of the Japanese pollock fishery in the eastern Bering Sea.

2.2 Annual change in fishing efficiency

The number of pair trawlers by vessel size-class active in the pollock fishery during 1965-72 is shown in Table 3. It is obvious that the vessel size is becoming larger year by year. The power of engine also becomes larger. Therefore the fishing efficiency of pair trawlers is considered to have increased in these years. When the catch per unit effort is used for monitoring stock abundance, a correction for the change in the fishing efficiency should be made. Takahashi (1974) reported on this problem for the Japanese pollock fishery in the eastern Bering Sea. He discussed in detail the determinants and the annual change in the fishing efficiency for several fishing gears in the pollock fishery. Maeda (1972) also examined the relationship between fishing power, measured by catch per unit effort (CPUE), and power of engine (PS) for pair trawlers in the pollock fishery in the eastern Bering Sea. He obtained the following equation for the relationship:

$$CPUE = 1.24 + 0.02\ PS$$

Average vessel size, power of engine, and relative fishing efficiency derived from Maeda's equation are shown in Fig.2. The fishing efficiency is calculated relative to the fishing power in 1968 which is selected as the standard fishing power because the substantial development of the fishery is considered to have been nearly completed in that year.

The finally corrected catch per unit effort (CPUE'') is obtained by applying the relative fishing efficiency to the CPUE' (Fig.3). The difference between CPUE'' (Fig.3) and CPUE' (Fig.1) is large especially after 1969. The difference is so large that an opposite conclusion can be drawn about the change in stock abundance.

The average density index (ADI) for pollock is calculated by the method reported by Doi (1971). That is

$$ADI = (\sum B_i \cdot CPUE''_i)/\sum B_i$$

where B_i is the area of fishing grounds in a statistical block (1° in longitude and 30' in latitude) and $CPUE''_i$ is the catch per unit effort in the same block. The result obtained is shown in Fig.3 together with the CPUE''. It is noted there is no large discrepancy between ADI and CPUE''. ADI estimated through these procedures is considered to be the best available index at present for monitoring stock abundance.

3. PACIFIC OCEAN PERCH FISHERY

Pacific ocean perch (POP) in the Bering Sea mostly inhabit the continental slope in the eastern Bering Sea and along the Aleutian Islands. They hardly change their habitat by season and are taken by trawl during almost all of the year. There are two stocks, one in the Eastern Slope region and the other in the Aleutian region. These two stocks should be treated separately because of different biological characters.

A method to estimate an index of stock abundance was reported by Chikuni (1974). The author reviews the method here.

The catch of POP by gear during 1963-72 is shown in Table 4. The stern trawl achieved the largest catch through the years in both regions. As the fishing efficiency varies by fishing gear, the standard gear should be selected. The stern trawl is considered to be the most appropriate gear for this purpose.

3.1 Difference in fishing efficiency with vessel size

Vessel size of stern trawlers engaged in the POP fishery in the Bering Sea was mostly in the range of 2 500-3 500 gross tons in early years, but has varied widely since the mid-1960s, and ranged from 250 to 4 000 tons in recent years (Table 5). Vessels of 2 500-3 500

Table 4

Catch of Pacific ocean perch in thousands of metric tons by fishing gear for the Japanese fishery in the Bering Sea

Year	Pair trawl	Danish seine	Side trawl	Stern trawl	Others	Total
1963	5.8	10.9	1.6	-	-	18.3
1964	5.5	10.5	16.2	13.1	-	45-3
1965	-	1.0	27.2	18.9	+	47.1
1966	0.3	2.0	25.9	21.9	0.4	50.5
1967	0.1	2.6	8.3	22.9	0.1	34.0
1968	-	3.7	1.4	47.2	-	52.3
1969	+	+	1.7	28.2	+	29.9
1970	+	-	+	23.1	+	23.1
1971	+	+	0.1	24.2	+	24.3
1972	0.1	+	+	14.7	+	14.8

Table 5

Catch of Pacific ocean perch in metric tons by region and vessel size for the Japanese stern trawl operated in the Bering Sea. The statistics for the land-based drag-net fishery are excluded because the data by vessel size are not available

Vessel size (tons)	200-300	300-500	500-1000	1000-1500	1500-2500	2500-3500	3500-	Total
Eastern Slope Region								
1964	-	-	-	-	60	1 143	-	1 203
1965	-	-	-	-	-	1 153	672	1 825
1966	65	4	86	-	-	1 707	2 443	4 305
1967	1 350	919	745	-	-	2 919	1 348	7 281
1968	713	4 570	728	2 311	544	10 498	1 635	20 999
1969	512	3 711	105	268	84	3 059	2 206	9 945
1970	117	222	38	98	296	3 872	1 515	6 158
1971	139	1 320	28	202	998	1 843	504	5 034
1972	1	1 200	317	6	406	617	1 306	3 853
Aleutian Region								
1964	-	-	-	-	4 166	7 627	-	11 893
1965	652	-	7	-	-	8 981	6 912	16 552
1966	-	-	363	-	-	6 789	6 508	13 660
1967	-	3 346	2 006	-	-	471	3 383	9 206
1968	-	12 152	295	32	2 700	6 723	489	22 391
1969	4	7 231	488	-	4 475	1 195	140	13 533
1970	-	2 383	1 028	-	7 804	154	0	11 369
1971	-	3 334	1 065	703	5 011	2 202	532	12 847
1972	-	3 526	1 634	690	2 328	355	135	8 668

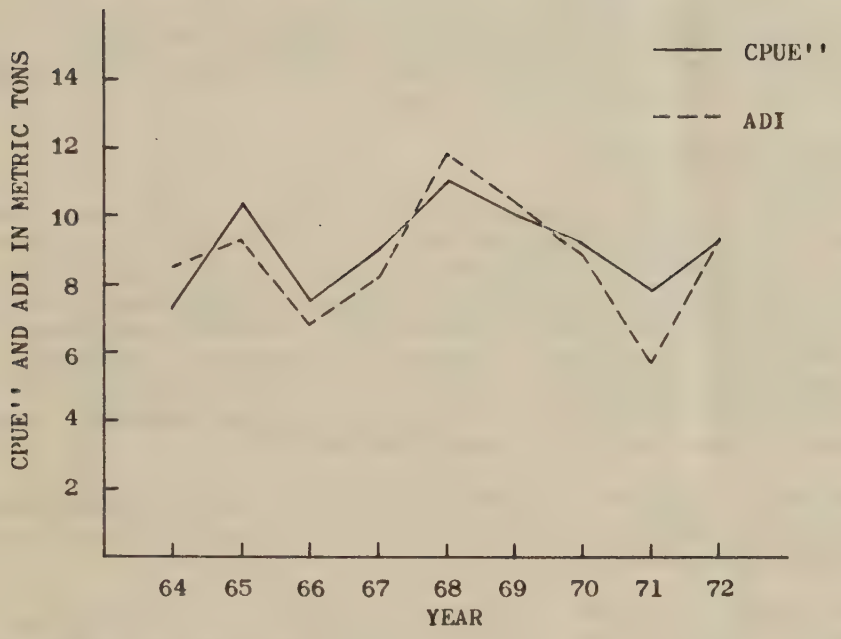

Fig.3 Catch per unit effort of pollock corrected with the annual change in fishing efficiency (CPUE'') for pair trawl of the Japanese fishery in the eastern Bering Sea. Average density index (ADI) is derived from the CPUE''.

tons achieved the largest catches through the years in both regions. Since the fishing efficiency varies with vessel size, it is necessary to select a standard size-class to figure out the catch per unit effort (CPUE). Catch per unit effort (for one hour of hauling) calculated by vessel size shows a dome-shaped variation against the vessel size, and vessels of 2 000-3 000 tons show the highest CPUE (Fig.4). A similar pattern can be recognized more clearly for the POP fishery in the Northeast Pacific Ocean where the vessels depend more heavily on POP (Chikuni, 1971). Chikuni (1971) examined and reported a method to standardize the fishing effort of the fishery based on this pattern.

It is considered appropriate to select the 2 500-3 500 ton class as the standard size-class in work with the statistics because of the large amount of catch through the years and the high value of CPUE for vessels in this class.

3.2 The bias of apparent CPUE

Any vessel in the POP fishery does not depend solely on POP. Some hauls are directed to POP on one day or at one time, but other hauls on other days or at other times are directed towards other species. The results of these various kinds of operations directed to various target species are combined in the statistics without any indication of the target species. In other words, it can be said that the catch statistics for the POP fishery are mixed up with the statistics for the other fisheries. Consequently, not only is the relative weight of the POP catch in the statistics made smaller by the catch of other species, but the CPUE calculated from the statistics is also depressed because it includes the effort expended to catch the other target species.

On the other hand, the catch proportion of POP in a haul is considerably large when the operation directed to POP is a success, since the operation is performed after a fish school is detected by echo-sounder.

The apparent proportion of POP in the catch statistics of the standard size-class stern trawl is shown in Fig.7. The proportion of POP has been decreasing in both the Eastern Slope and Aleutian regions. This phenomenon indicates that the stern trawl has been increasing its operation directed to the other species in recent years. A radical change took place in the Eastern Slope region in 1969 resulting from the drastic increase in pollock catch.

The correlation between CPUE and catch proportion of POP (%) calculated for the smallest statistical unit (i.e., statistical block, month, and vessel size-class) shows clearly the direct proportional relationships in all vessel size-classes (Fig.5). The difference in the slope of regression line by vessel size-class indicates the difference in the fishing efficiency. The fact that the relationship is recognized clearly through all size-classes indicates that the bias in the apparent CPUE originating from the statistics directed to the other target species must be involved, regardless of the vessel size, in the relationship between apparent CPUE and catch proportion of POP. Therefore, it is considered that the bias of the apparent CPUE can be corrected in the light of the relationship.

Since the CPUE changes according to the size of the proportion of POP catch, the observed CPUE value should be corrected to a standard value of the proportion in the catch. The correlation and the regression line between CPUE and catch proportion of POP for the standard vessel size-class are obtained annually (Fig.6). Meanwhile, such high values of the catch proportion as 90-95% are observed for the catch statistics in the Aleutian region in early years, and these are considered to be the results of operations directed mostly at POP. Taking account of this fact, the catch proportion of 95% is chosen here as the standard catch proportion for the POP fishery in the Bering Sea. The corrected catch per unit effort (CPUE') is calculated by adjusting CPUE to the level observed at a catch proportion of 95% according to the regression line in each year (Fig.6). The comparison of CPUE' is shown in Fig.7 together with the proportion of POP catch in the statistics. The CPUE' obtained through the procedures described above can be regarded as the best available index

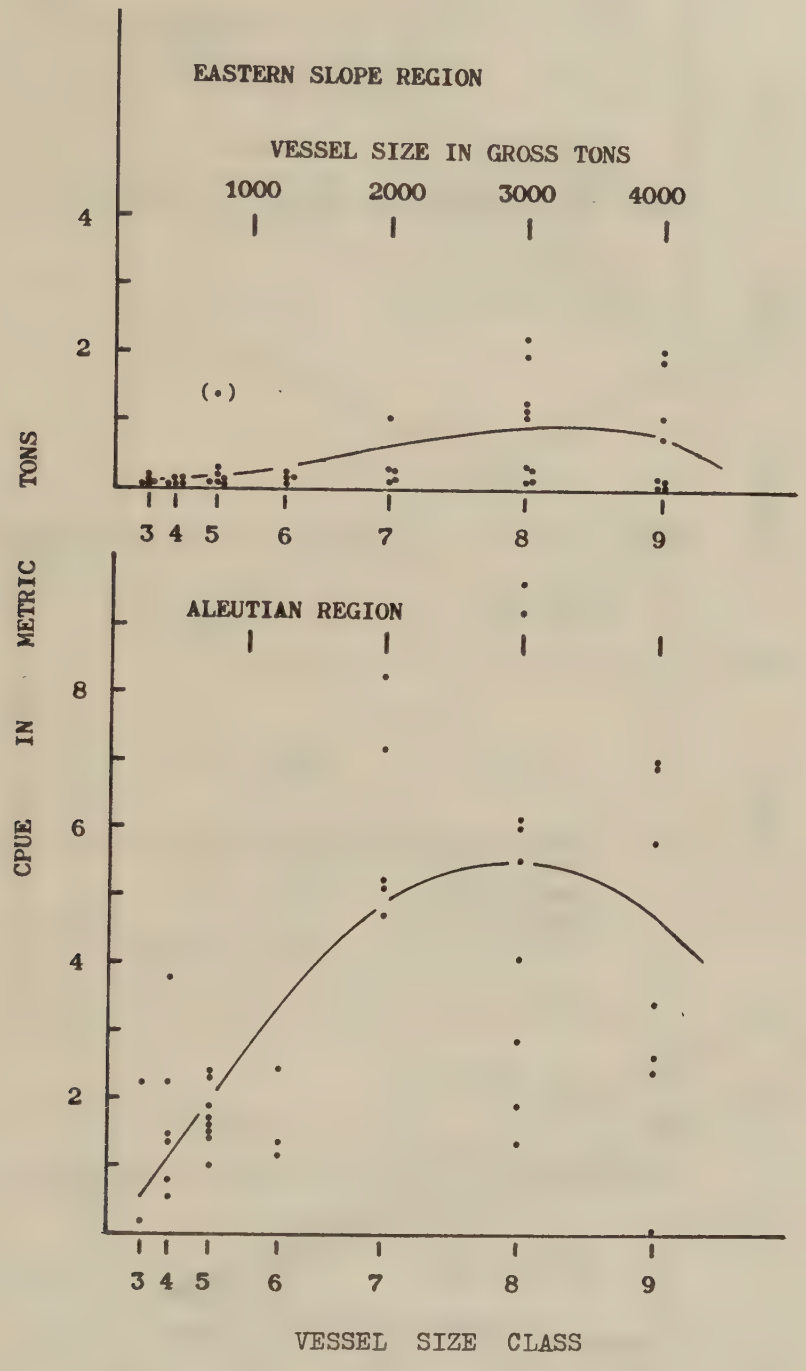

Fig.4 Relationship between vessel size and catch per unit effort (CPUE) of Pacific ocean perch for stern trawl of the Japanese fishery in the Bering Sea during 1964-1972.

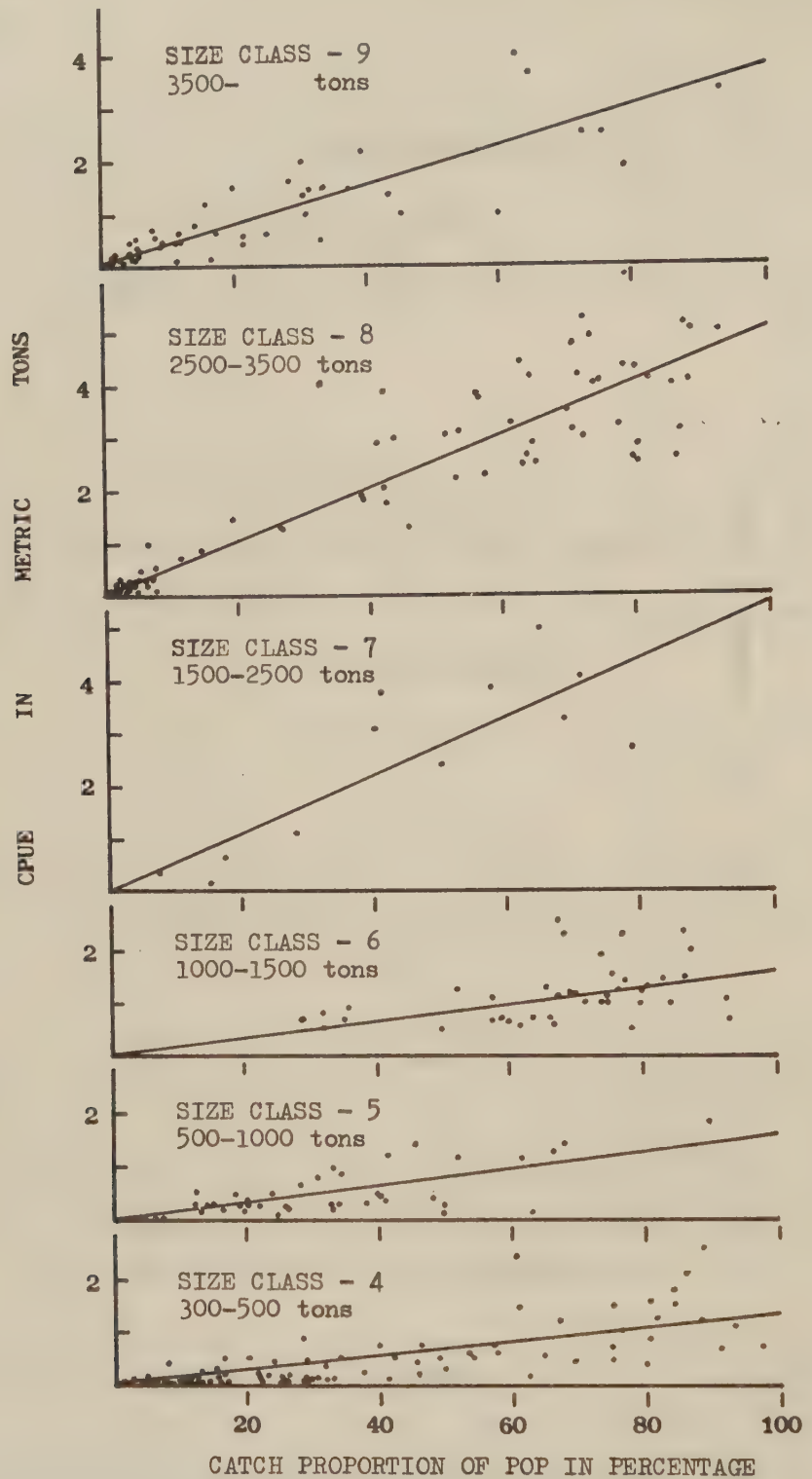

Fig.5 Relation between CPUE and catch proportion of Pacific ocean perch calculated by statistical block and month by vessel size-class for stern trawl of the Japanese fishery operated in the Eastern Slope region in 1968.

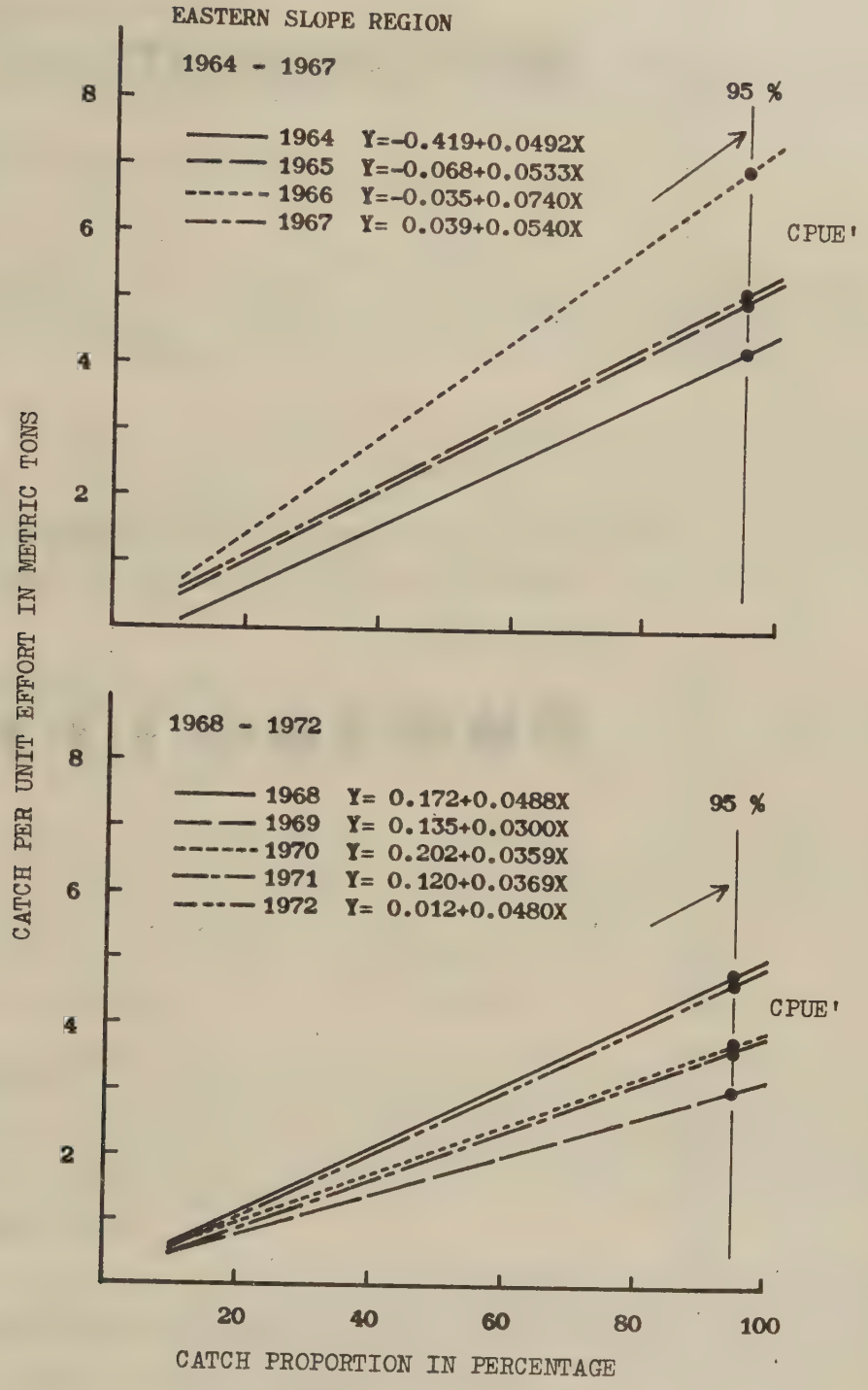

Fig.6 Annual change in the relationship between CPUE and catch proportion of Pacific ocean perch for the standard size-class stern trawl of the Japanese fishery operated in the Eastern Slope region during 1964-1972. Corrected CPUE' is estimated applying 95% of catch proportion to the regression line in each year.

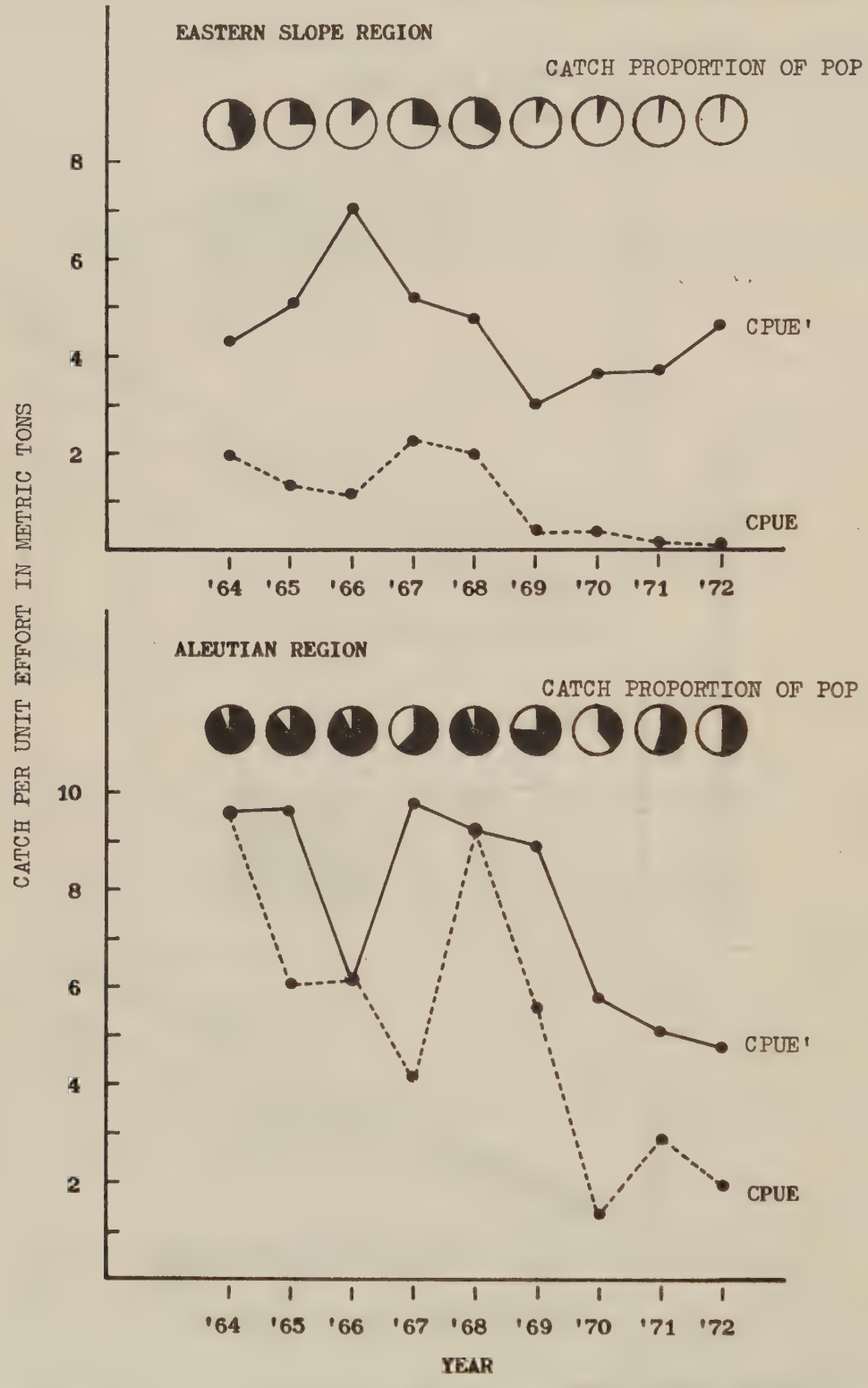

Fig.7 Difference between CPUE' and CPUE of Pacific ocean perch for the standard size-class stern trawl of the Japanese fishery operated in the Bering Sea during 1964-1972.

for monitoring the abundance of the Pacific Ocean perch in the Bering Sea at present.

4. DISCUSSION

Problems involved in monitoring stock abundance in the Bering Sea can be classified into three major subjects, and each subject seems to be common to the groundfish fishery in general.

4.1 Evaluation of effective fishing effort

4.1.1 Target species

Every effort should be made to evaluate the effective fishing effort directed to the particular species concerned. In the case of the pollock fishery (which must be rather rare in this respect), it seems effective to use the statistics from vessels with special processing equipment, since the equipment is for a specific target species.

A freezing plant, however, cannot be connected with any one target species since the plant is available optionally for any species. In fact, the vessel which is equipped only with a freezing plant always operates in multi-target fisheries such as the POP fishery. The results of the operations directed at several target species are combined in the statistics, and the effort for any species is more or less biased on the high side. The ideal method to avoid the bias is, of course, to breakdown the statistics with a category for each target species. But it is very difficult to prepare such statistics since there are complicated problems in sorting the data by target species.

Unless the statistics by target species can be prepared, there is no way but to apply an indirect method for the evaluation. For example, one possible method is to sort the statistical data for a fishery according to the ranking of species in the daily catches which was shown in the example for the pollock fishery. The method used for the POP fishery is considered to be another new way to correct the bias.

In the method applied to the POP fishery, no special information is required other than catch statistics. The statistics, however, have to be prepared in sufficiently small statistical units to analyse the relationship between CPUE and catch proportion. Of course the method still involves such hazards as the risk of over-estimation due to fixing the standard catch proportion at 95%. These problems merit further analysis.

4.1.2 By-catch species

There is no good way at present to evaluate the effective fishing effort for by-catch species which are taken along with specific target species. If a fishery takes the incidental species in large quantities, there may be some way to calculate CPUE. However, the species which are taken in small quantities by any fishery (such as Pacific cod, flathead sole, rock sole, and turbot) are very difficult to deal with. The apparent CPUE calculated from statistics for any species among them is not reliable even if the total amount of the catch is large.

A new method under a new assumption is required to monitor the abundance of these by-catch species. A solution in the form of a multi-CPUE, multi-proportion model may possibly be available. It is essential that the status of the by-catch species, and their quantitative relationships with both target species and other by-catch species, should be investigated in detail to get a practical working hypothesis in connection with the development of a new method.

4.2 Fishing gear, vessel size, and fishing efficiency

Nearly all of the groundfish species in the Bering Sea are taken by several gears. This situation makes it necessary to investigate and select an appropriate standard gear as was done in the two examples in this paper.

When the sizes of vessels with the standard gear are very diverse, the differences in fishing efficiency also have to be investigated and an appropriate standard size selected if necessary.

Besides these treatments, the annual change in fishing efficiency of the standard gear or standard vessel size have to be checked also. If the fishing efficiency changes substantially by year, a correction should be made by some method such as in the example described for the pollock fishery. The information other than catch statistics necessary to get the proper measures of fishing power have to be collected and examined.

One of the important elements related to fishing efficiency, which have not yet been dealt with in this paper, is the learning effect. It is very difficult to deal quantitatively with such things as knowledge of the fishing grounds and behaviour of fish, or experience in fishing tactics and operation of the gear. However, these things deserve further consideration because the learning effect seems to have a large influence on fishing power.

4.3 Coverage of the area

In the examples in this paper, the extent of the fishing grounds was taken into consideration for the pollock fishery, but not for the POP fishery. Consideration of the extent of fishing grounds is essential in monitoring the abundance of pollock because the location and the extent of fishing grounds change by season and year due to the seasonal migration of fish and the annual change in the migration pattern. As for POP, on the contrary, the location of fishing grounds does not change so much as described before, but the extent of the fishing grounds changed during the development of the fishery in early years.

In spite of the difference in this respect between the two examples, the feature which is common to them is that the area to which the catch statistics refer is in fact only the area in which the actual fishing operations were performed in the year. Despite this, it is usually assumed that the extent of fishing operations cover the habitat of the stock as a whole. It is usually very difficult to know whether the assumption is true and no clear solution has yet been obtained even in the cases described.

It should be noted that at present the indices for monitoring stock abundance cannot be free from the suspicion of bias unless the assumption is satisfied. Fishing operations are apt to locate the higher densities portion of the stock because fishermen, of course, direct their operations to concentrations of fish. This is one of the reasons why the indices are suspected.

The annual change in the migration pattern of fish like pollock and the change in the location or extent of the fishing grounds which occur in both pollock and POP fisheries make the analysis of this problem more difficult. Further investigation is needed.

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CATCH PER UNIT EFFORT IN LONG RANGE NORTH ATLANTIC DEMERSAL FISHERIES, AND ITS USE IN CONJUNCTION WITH COHORT ANALYSIS

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CONTENTS

		Page
1.	THEORETICAL BACKGROUND	38
2.	PRACTICAL PROBLEMS IN THE ESTIMATION OF PARAMETERS	38
3.	CURRENT CLIMATE OF OPINION CONCERNING THE UTILITY OF C.P.U.E. ANALYSIS ON TRAWL FISHERIES	39
4.	PRELIMINARY INVESTIGATION OF ASSUMPTIONS UNDERLYING C.P.U.E. ANALYSIS USING COHORT ANALYSIS	42
	4.1 Variation of catchability with seasonality: West Greenland cod fishery	42
	4.2 Variation of catchability with stock size: Arcto-Norwegian cod	42
5.	SUMMARY	46
6.	REFERENCES	50

1. THEORETICAL BACKGROUND

Following the theory and notation relating to exploited fish populations as summarized by Gulland (1969, p. 45) the catch per unit effort (c.p.u.e.) is proportional to the average density (D) of the stock over a specified time period, and if the area inhabited by that stock remains constant the c.p.u.e. will also be proportional to the average abundance ($\bar{N}$), the coefficient of proportionality being the catchability coefficient (q). The interest of the estimate of abundance is its use as a measure of change in stock abundance in successive time intervals either as a gross population change in production models, or to estimate mortality for use in analytical models.

The conventional procedure in c.p.u.e. analysis is to estimate total mortality as the $\log_e$ ratio of abundance in successive time intervals, but having in mind the assumptions defined by Gulland where

$$\frac{\text{c.p.u.e.}_2}{\text{c.p.u.e.}_1} = \frac{n_2}{n_1} = \frac{q_2 A_1 \bar{N}_2}{q_1 A_2 \bar{N}_1},$$

a more rigorous estimate of total mortality (F + M), following Beverton and Holt (1957, p.179), would be

$$(F + M)_1 = \log_e \frac{\bar{N}_1}{\bar{N}_2} + \log_e \frac{q_1}{q_2} + \log_e \frac{A_2}{A_1} + \log_e \left\{ \frac{(F + M)_1 \left(1 - e^{-(F + M)_2}\right)}{(F + M)_2 \left(1 - e^{-(F + M)_1}\right)} \right\}$$

The conventional procedure assumes the last three terms are zero. With regard to the final term this states that total mortality remains constant through both periods. If so then the estimate of mortality could as well be based on the ratio of catches. The use of c.p.u.e., rather than catch, recognizes the common observation that mortality is seldom constant. The error is small in relation to other difficulties in estimating total mortality ($\pm$ 10 percent when F varies $\pm$ 0.2), but new problems arise when in the next step of analysis separate estimates of F and M are obtained by regression $(F + M) = qf + M$ because the variables are not independent. These theoretical snags may not be a major source of error but continued with the variability of the data they prevent statistically satisfactory testing of the underlying hypotheses, with the result that the frequent criterion of a measure of effort is that it should be proportional to F with q a constant. It is not possible to deduce whether this is an oversimplification.

2. PRACTICAL PROBLEMS IN THE ESTIMATION OF PARAMETERS

The familiar problems summarized above are often overlooked by analysts because of more serious difficulties in measurement of c.p.u.e. which arise through the basic assumptions regarding A and q when the data cover a time series. The catchability coefficient is itself a compound variable with components that have been categorized in contributions to the ICES Symposium on the Measurement of Abundance of Fish Stocks (1964). It is sensitive to:

(i) changes in fishing power of the effort unit;
(ii) changes in biological availability of the resource;
(iii) changes in the relative distribution of fish and fishing.

For convenience variation in the area inhabited by the stock may be regarded as a special case under (iii). Any one of the components will exhibit random variation, perhaps real or through error in estimation, but they may also exhibit trends over time dependent on the density of either fish or fishing or both.

The initial technical difficulty arises in the choice of unit of effort which is likely to show least bias over a time series of data. For example, Hodder (1966) identifies vessels of a particular size and fishery objective as a basis for estimates of c.p.u.e. in the Newfoundland haddock fishery. Wiles and May (1967) then give a very full description of the kind of problem encountered in developing a reasonably standardized estimate of c.p.u.e. into a derived estimate of effective fishing effort in a variable international fishery. This introduces an initial adjustment of data. Fisheries are characteristically heterogeneous with respect to countries and usually with respect to gear, etc. Estimates of gross fishing effort are therefore associated with an amalgam of catchability coefficients unique to each country/gear and it is customary to simplify the analysis by expressing effort in effective effort units, i.e. the number of effort units of a fleet composed of standardized vessels exerting the catchability characteristic of the standard fleet. Clayden (1972) has carried out such an analysis of English distant-water cod fisheries, using also a correction for fishing power of the standard fleet based on the average tonnage of the vessels concerned. His analysis of the regression $Z = qf + M$ revealed only one relationship which was significant ($P < 0.05$) out of nine examined.

A different aspect of the same problem is revealed in an analysis by the Joint ICES/ ICNAF Working Group on North Atlantic cod stocks (ICES 1973). The Group investigated the variation in F deduced from cohort analysis (at assumed M) with effective fishery effort deduced by c.p.u.e. analysis of a standard fleet. In this instance the standard fleet had not itself fished in all the cod stocks examined, so the analysis was sustained by conversion based on correlations between fleets where the appropriate fleets had fished 'together'. The results are illustrated in Figure 1. The variance about these regressions reflects the error in estimation of effective fishing effort, or the catchability coefficient with an additional variance caused by the standardization procedure outlined above.

The general experience and overall utility of this level of c.p.u.e. analysis is best summed up by an analysis on Gulf of St. Lawrence cod by Paloheimo and Kohler (1968). They took account of vessels and seasonal changes in fishing and, by analysis of variance and covariance, detected significant differences in total mortality between years and between ages. But they were not able to detect significant changes in total mortality between two time periods associated with an obvious change in the level of fishing and they concluded that changes in catchability and/or natural mortality between years caused sufficient variation in total mortality to obscure any relationship between F and fishing effort that might exist.

3. CURRENT CLIMATE OF OPINION CONCERNING THE UTILITY OF C.P.U.E. ANALYSIS ON TRAWL FISHERIES

Catch per unit effort of commercial fishery data as an analytical tool became more difficult to interpret during the 1960s as rapid changes in fishing technology made it increasingly difficult to maintain a time series of consistent estimates. Moreover, the emerging need for advice on catch or effort quotas required additional information not explicit in c.p.u.e. analysis. There was and is a need to describe stock changes in terms of absolute values rather than as an index which has a variable calibration between whole stock areas, and especially between substocks of a larger stock which forms the management unit. It has also become critically important to estimate fishing mortality on the partially recruited age groups which in heavily exploited resources frequently provide a significant part of the catch and hence need to be incorporated in quota regulations. This area of mortality is not readily accessible in c.p.u.e. analysis.

Cohort analysis was developed to overcome the difficulties reviewed above. It does have its own technical disadvantages:

(i) the need to assume a value of natural mortality (though in this respect, because of the statistical problems, it is no different from assessments based on the results of c.p.u.e. analysis);

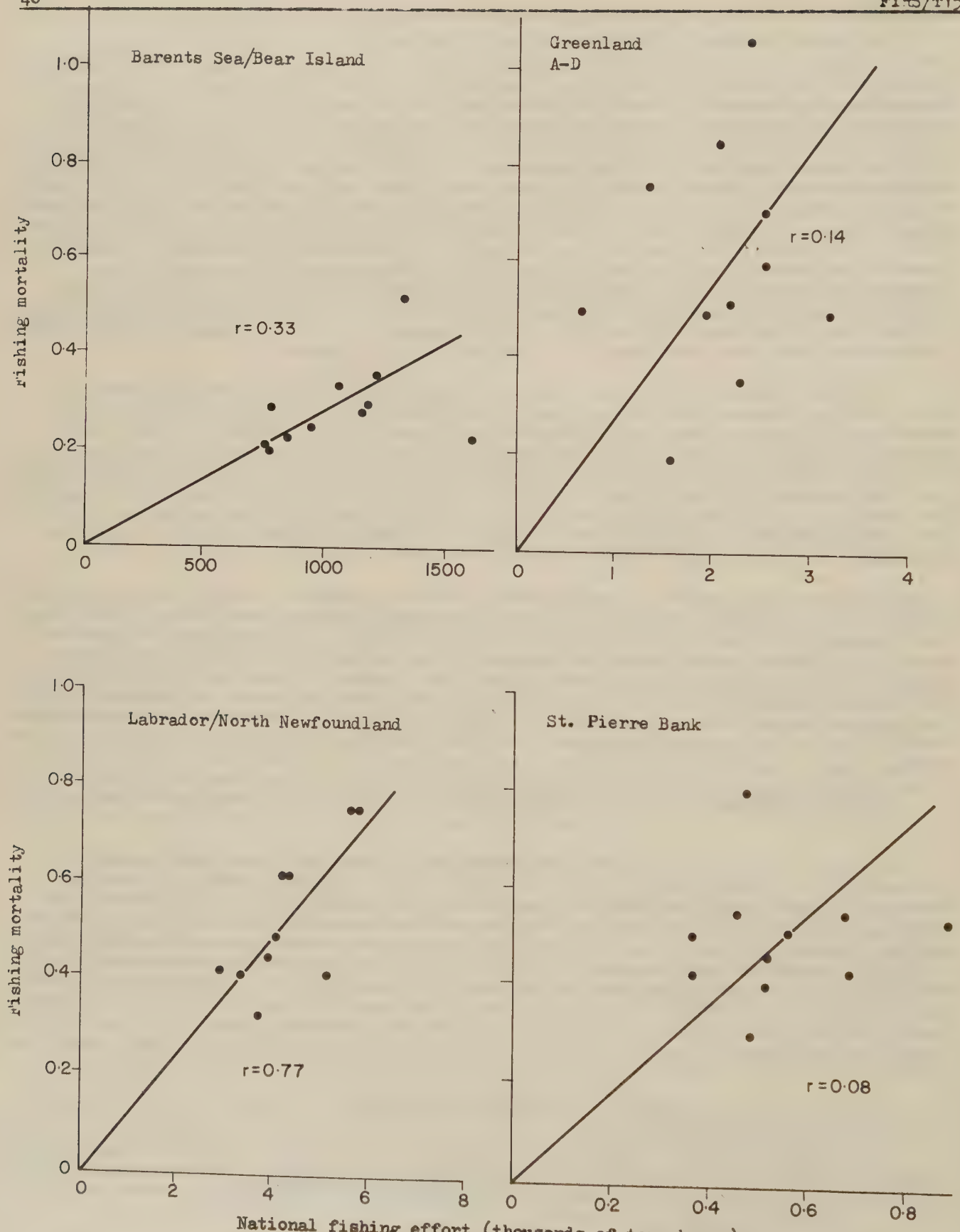


Fig. 1 Relationship between fishing mortality (cohort analysis) and national fishing effort (c.p.u.e. analysis) in selected north Atlantic cod stocks.

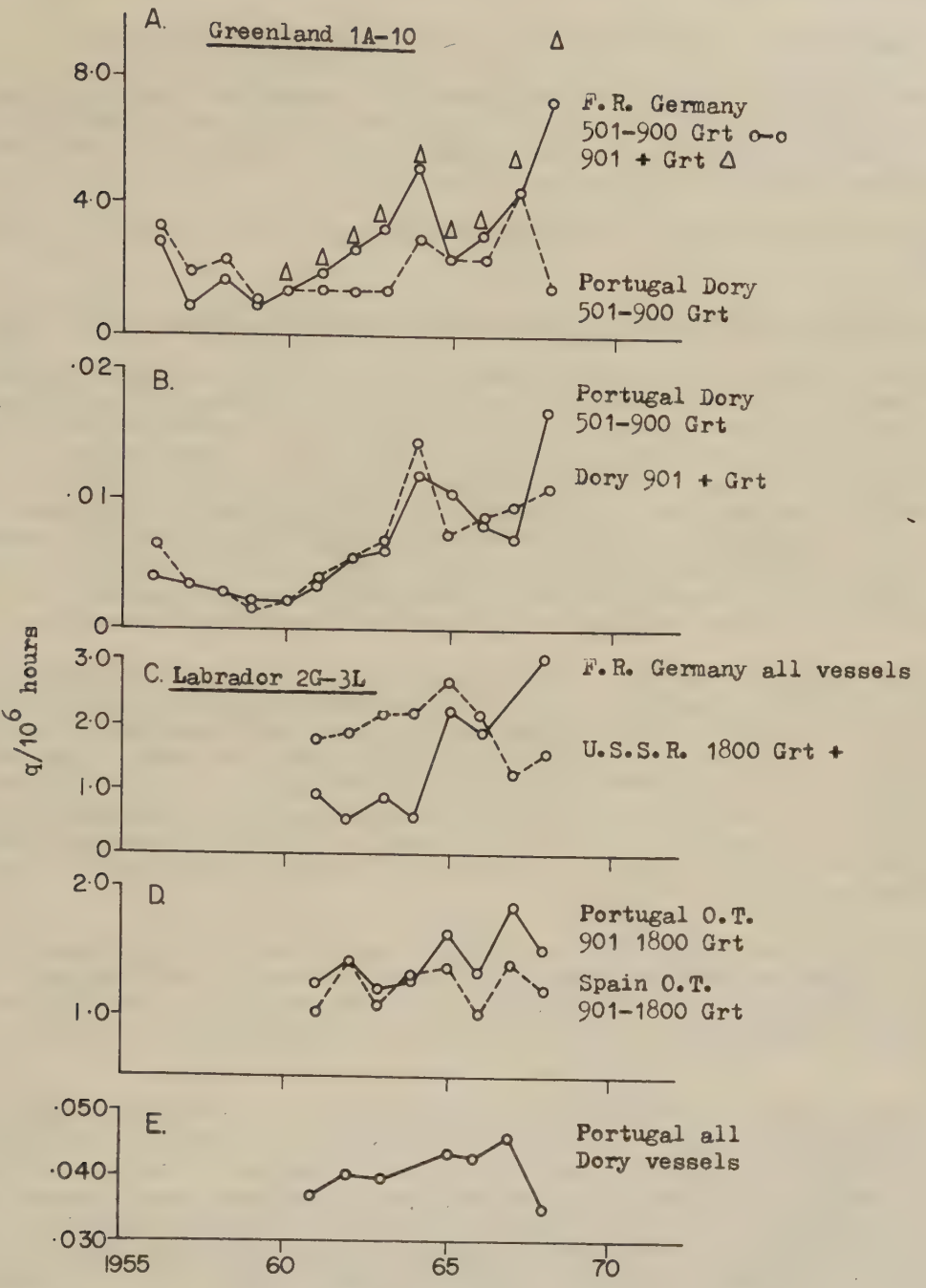


Fig. 2 Variations in the catchability coefficient, 1955–68, for selected fleets at Greenland (ICNAF Div. 1A–D) and Labrador (ICNAF Div. 2G–3L).

(ii) the assumption that all fish in the stock become available to the fishery at some time in their life;

(iii) the assumption of terminal values of F to initiate the analysis.

It has proved useful in practical management but, perhaps as important, cohort analysis provides an independent measure of F which can be used to test more effectively the proportionality F = qf and the validity of c.p.u.e. data. This possibility is explored below using two examples from North Atlantic cod fisheries.

4. PRELIMINARY INVESTIGATION OF ASSUMPTIONS UNDERLYING C.P.U.E. ANALYSIS USING COHORT ANALYSIS

4.1 Variation of catchability with seasonality: West Greenland cod fishery

The ICES/ICNAF Group (ICES 1973) estimated F on cod at West Greenland (ICNAF SA 1 Div. A-D) and at Labrador (ICNAF SA 2/3 Div. 2J-3L) by cohort analysis. This fishing mortality generated by the international fishery has been partitioned between national fleets according to national catches, and this related to fishing effort in national units. The catchability coefficient for several of these fleets is reasonably stable indicating that the effective fishing effort has been properly measured and that the c.p.u.e. would provide a satisfactory index of abundance. There is however an apparent increase in catchability of cod to the fleet of the Federal Republic of Germany (FRG) in both stocks and, though there is a similar effect for Portuguese dories at Greenland this is not apparent for dories fishing at Labrador, although the same vessels are involved in both fisheries.

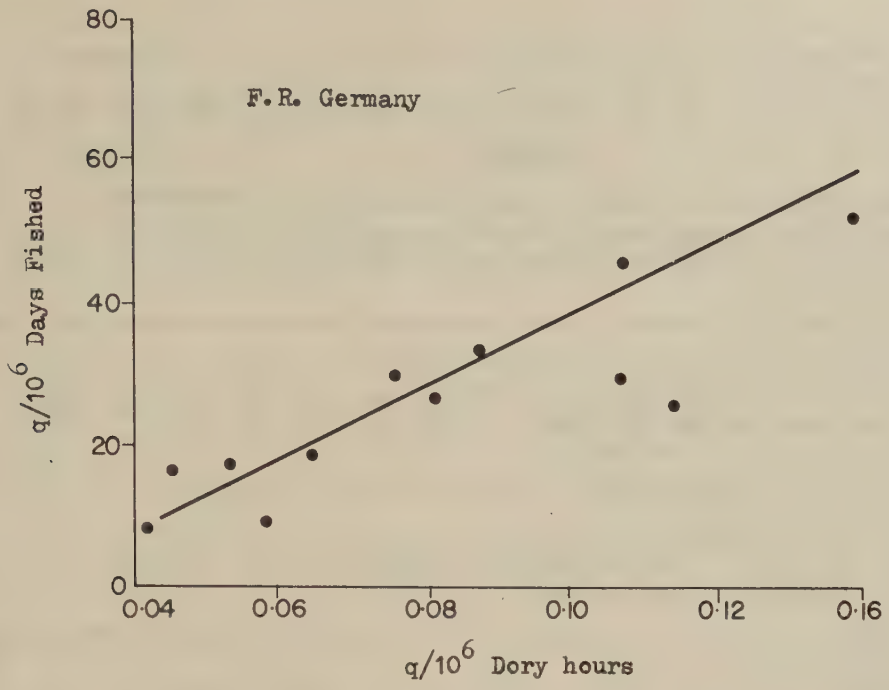
The trend in q for FRG vessels at Labrador reflects changes in the fleet itself, and probably in its objectives, redfish being less predominant in recent years. However, the similarity in trends in q for both trawlers and dories at West Greenland (Figure 3A) suggests some broader effect. The change in q is rather greater than the overall change in F in the period so that, if the result were a statistical artefact in national effort or catch data, then it would have had to affect both fleets equally. This seems unlikely and suggests some real change in q. Figure 3B relates the change in q for FRG trawlers to the stock size derived from the mortality estimates. These are not entirely independent but the trend line suggests some effect of stock size on q.

The possibility remains that the trend in q is not caused by the change in stock size per se, but by changes in the fish/fishery interaction whereby fishing is most intense at the season when the fish are most concentrated, i.e., a reduction in area of the stock through biological reasons, as opposed to a reduction in area caused by reduced total stock abundance.

Table 1 summarizes at a very gross level changes in the distribution of FRG trawler effort at West Greenland, both in area and in season, and its effect on the average effectiveness of a unit of trawler effort deployed at West Greenland. The seasonal peak of activity became marginally later, and effort as a whole was more evenly spread throughout the year in the period 1962-67 and, although the area distribution was static in those years, over the period as a whole the centre of fishing effort has shifted from the northern divisions A-D to the southern divisions E-F. This alone accounts for a 35 percent increase in the average effectiveness of a unit of effort through the period and one would have to conclude that the catch per unit effort of this fleet would not be a reliable guide to changes in stock abundance owing to the changes in the structure and pattern of fishing activity.

4.2 Variation of catchability with stock size: Arcto-Norwegian cod

A number of English scientists have analysed and re-analysed national data for Arcto-Norwegian cod at different times and by different methods. Typical estimates of q show a range of values. Some of these estimates are summarized in Table 2 to show the efficacy



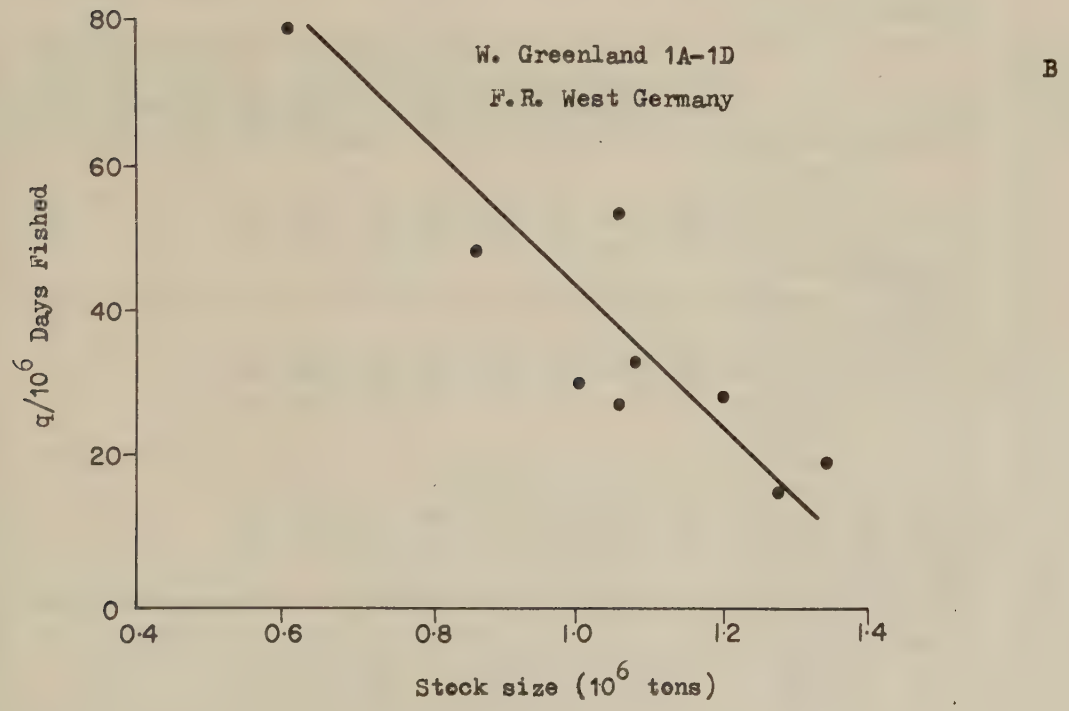


Fig. 3 A. The relationship between catchability of cod at Greenland (ICNAF Div. 1A–D) for otter trawlers of the Federal Republic of Germany and Portuguese dories.

B. The relationship between catchability to Federal Republic of Germany otter trawlers and stock size at Greenland (ICNAF Div. 1A–D)

Table 1

Variations in the season/area distribution of fishing by FRG at West Greenland

	% distribution of annual days fished (all vessels)		Seasonal distribution of q (ICES 1973)	
	1957–61 1968–72	1962–67	Div. A–D	Div. E–F
January	4.7	9.1	4.18	3.37
February	4.7	7.6	4.05	3.85
March	4.8	7.9	4.44	4.81
April	5.0	6.8	3.29	6.50
May	14.5	7.1	3.68	7.22
June	27.3	12.1	3.16	6.40
July	15.5	15.2	2.63	3.61
August	10.5	8.2	1.68	1.92
September	3.9	5.0	1.08	2.02
October	2.2	4.6	1.22	2.07
November	2.3	6.7	2.63	2.31
December	4.6	10.3	3.35	2.74

	% distribution of FRG annual fishing effort		Weighted effectiveness per average unit annual effort*		
	Div. A–D	Div. E–F	Div. A–D	Div. E–F	Total
1956	93	7	282	33	315
1957	95	5	288	24	312
1958	74	26	224	123	347
1959	71	29	215	138	353
1960	64	36	194	171	365
1961	70	30	212	143	355
1962	67	33	206	133	339
1963	68	32	209	130	339
1964	69	31	212	125	337
1965	77	23	237	93	330
1966	67	33	206	134	340
1967	71	29	218	117	335
1968	61	39	185	185	370
1969	56	44	169	209	378
1970	29	71	88	337	425
1971	33	67	100	318	418
1972	29	71	88	338	426

*Weighted effectiveness per average unit annual effort = % distribution in year x $\sum_{1}^{12}$ (seasonal f_x x seasonal q).

Table 2

Estimates of catchability coefficient for Arcto-Norwegian cod stock, 1947-63, given as % of least squares accounted for by the regression coefficient q

	Method of analysis	
	Cohort	c.p.u.e.
	Effort unit	
	(F = qf)	(Z = qf + M)
Days absent	23	43
Total hours fished	59	86
Steam trawler hours fished	61	87
Steam trawler ton hours fished	81	83

of different effort units. The c.p.u.e. data were reached by weighting of the component fisheries on this stock (Garrod 1967). These estimates show an apparently good correlation with the various units of effort, except that the intercept M implied by the regressions was in most cases unconvincing. The regression F = qf, based on cohort analysis, shows a steady improvement with refinement of the effort unit and in no case was the intercept significantly different from zero (though that does not prove the assumed value M = 0.3).

The quality of the F = qf relationship from cohort analysis breaks down if the years 1964-72 are included, the best correlation being obtained using steam trawler units but accounting only for 47 percent of the sum of squares. The standard unit has in fact provided a progressively smaller sample of the fishery in recent years, but it is also true that since 1963 the stock and fishery have become more variable in size. It has become particularly obvious that the entry of a new strong year-class attracts increased fishing activity to the area with the younger age groups of cod as its primary objective (ICES 1974).

Pope and Garrod (1973) examined the problem from the standpoint of variations with q over time in the Barents Sea/Bear Island fishery by partitioning the fishing mortality on the total stock (including the Norway Coast fishery) between the geographical areas on the ratio of the catches in the different areas. The estimates were remarkably consistent over the period 1950-68 for the three main classes of vessels operating there, viz. U.K. steam trawlers q = 0.53 with σ = 0.11, U.K. motor trawlers q = 0.53, σ = 0.14 and U.S.S.R. trawlers q = 0.49, σ = 0.14. The three units also showed similar variations with time and the suggestion was made that this might be associated with stock size. The relationship is illustrated for both the Barents Sea/Bear Island fishery and for the Norway Coast fishery in Figure 4 where stock size is expressed in biomass.

The apparent trend of q with stock size in both areas has been examined further by relating the total fishing mortality to the total international fishing effort in English steam trawler units. The time series is at Figure 5, stock size here being expressed as the numbers of 5-10 year-old cod (the age groups used to estimate the mean annual fishing mortality). Regression between fishing effort and fishing mortality is highly significant, as implied by the stability of q in Figure 5, at least during the years up to 1963. But analysis of variance of the catchability coefficient in respect of numbers of 3-4 year-olds and 5-10 year-olds separately, showed no significant relationships. On the other hand, as the scatter diagram in Figure 6 shows over the period 1950-63 (solid points) there is a tendency for the catchability of 5-10 year-olds to increase with stock size of those age groups and to decrease when the newly recruited year-classes (3 and 4 year-olds) are more numerous. There is no statistical justification to select only these points but they do support the earlier conclusion from the proportion of s.o.s. accounted for by the regression of fishing mortality on fishing effort, that the character of this fishery has changed during the last decade since the fishery and the stock has become variable.

5. SUMMARY

The concept and use of c.p.u.e. analysis is associated with theoretical and practical difficulties which have led to high variance in the parameters estimated. Cohort analysis provides an independent estimate of fishing mortality which enables more effective analysis of fishing effort as an estimator. Two examples are given which indicate changes have occurred over time in the relationship between fishing mortality and the fishing effort measured by individual national statistics which would lead to difficulty in the interpretation of a time series of c.p.u.e. data. These may be related *inter alia* to changes in the seasonality of the fishery and hence its effective area at the time fished, or to changes in the age groups that provide the objective of the fishery if the seasonal availability varies with age. In principle, however, the analysis of fishing mortality derived by cohort analysis with independent estimates of fishing effort does provide a basis for rigorous investigation of the variation in catchability.

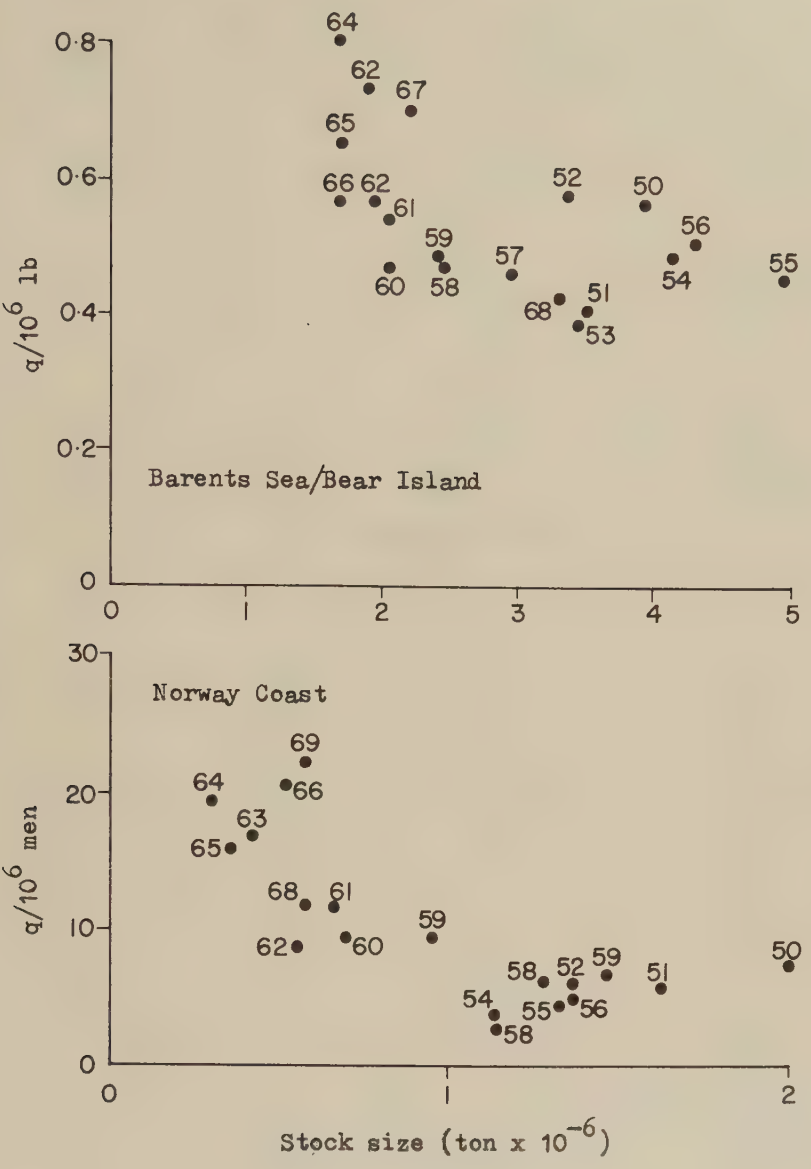


Fig. 4 Variations in the catchability with stock size for Arcto-Norwegian cod in the Barents Sea/Bear Island and Norway coast fisheries.

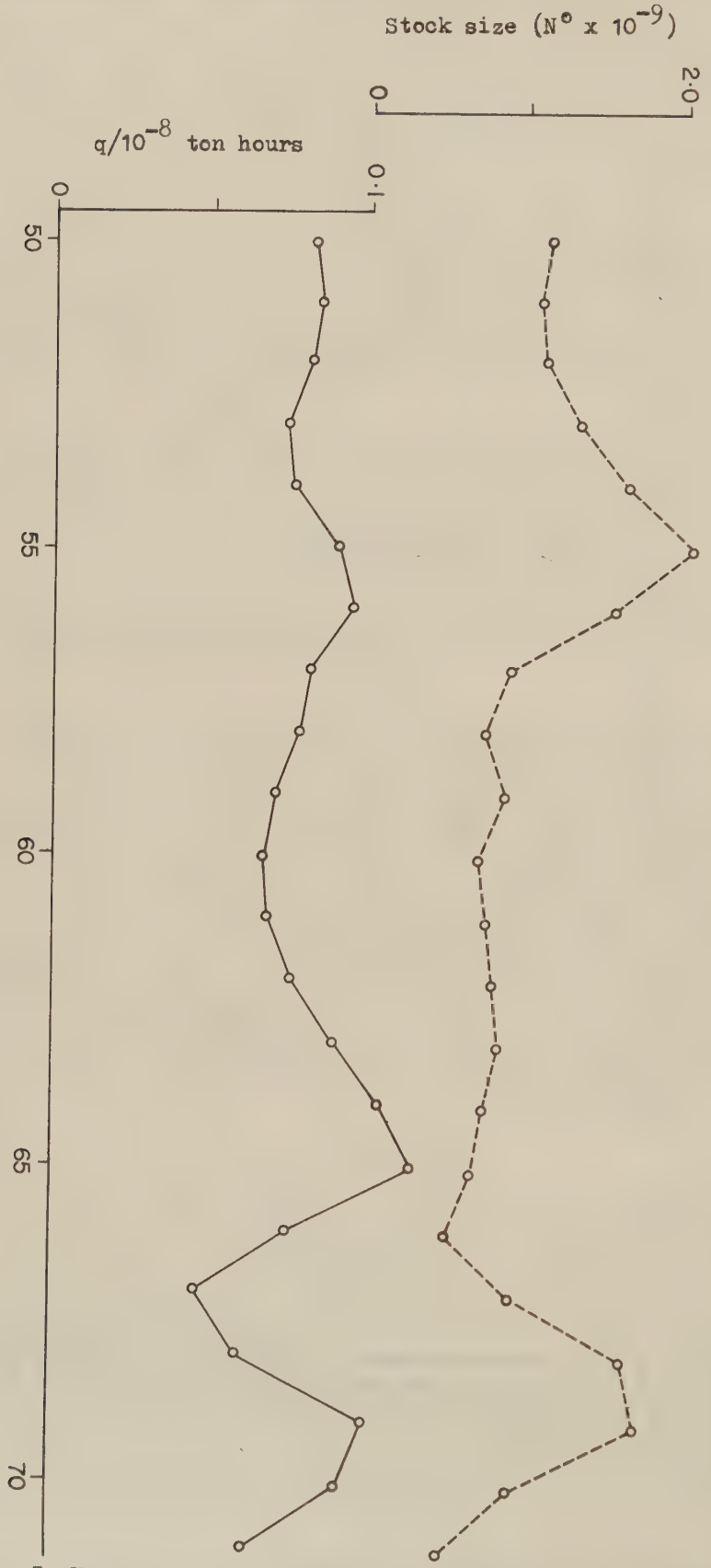


Fig. 5 Variation of catchability with time for Arcto-Norwegian cod compared to variation in numbers of 5–10 year old cod in the stock.

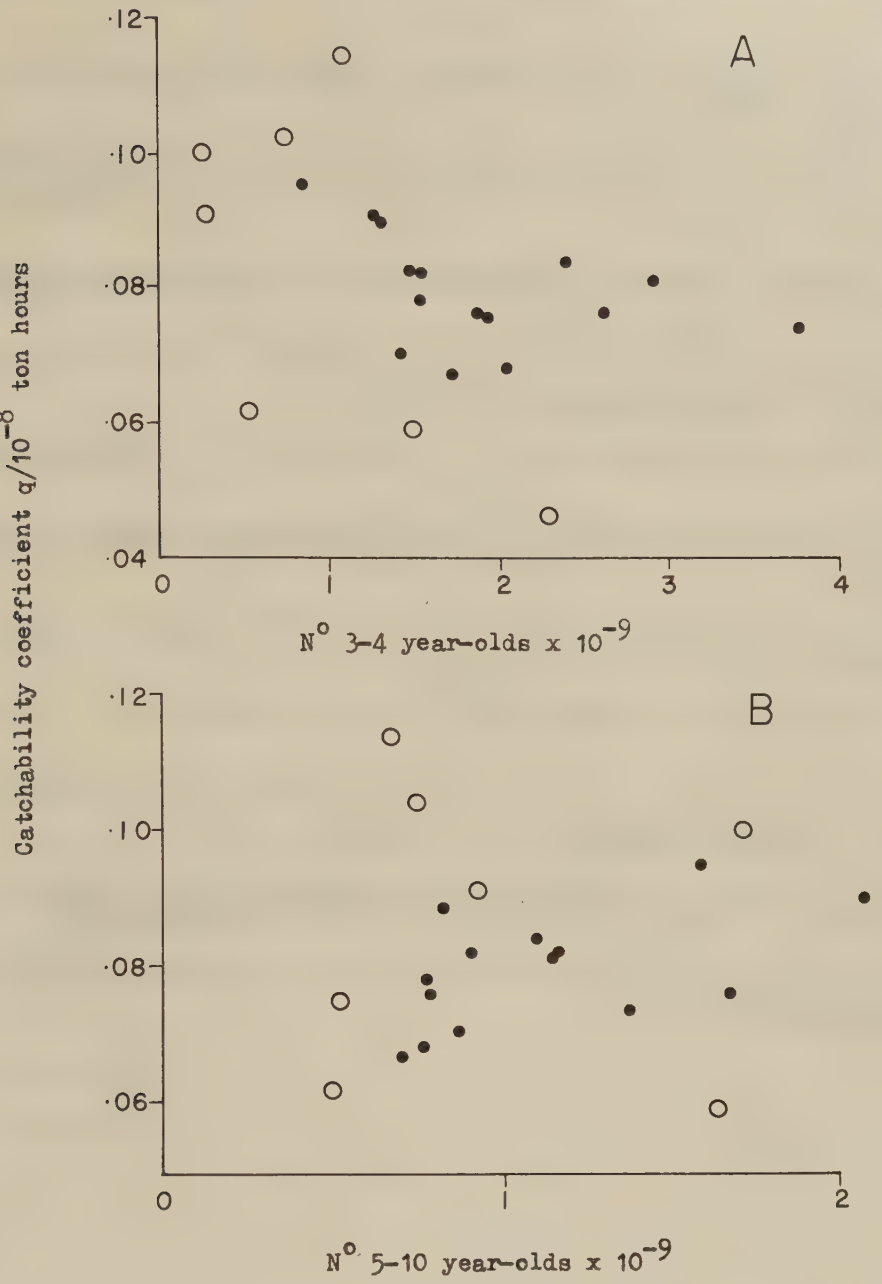


Fig. 6 A. Relationship between catchability and numbers of 3 and 4 year old cod in the stock.

B. Relationship between catchability and number of 5–10 year old cod in the stock.

Solid points, 1950–63. Open circles 1964–1970.

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THE CATCH PER UNIT EFFORT OF NORTH SEA HADDOCK, WHITING AND COD AS AN INDEX OF STOCK ABUNDANCE

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CONTENTS

		Page
1.	INTRODUCTION	52
2.	ESTIMATES OF STOCK ABUNDANCE	52
3.	CATCHES (LANDINGS) PER UNIT FISHING EFFORT	52
4.	RESULTS	52
5.	DISCUSSION	60
6.	CONCLUSIONS	60
7.	REFERENCES	61

1. INTRODUCTION

North Sea haddock, whiting and cod have been chosen for this study because these are species that have been studied intensively and, in the case of haddock and whiting, because there have been relatively large variations in stock abundance during the past 15 years.

The investigation has been confined to an analysis of trawl catches. Catches per unit effort from both commercial vessels and research vessels have been calculated, and these have been compared with estimates of absolute stock abundance based on virtual population analysis.

2. ESTIMATES OF STOCK ABUNDANCE

Estimates of stock abundance have been made using data supplied to the North Sea Roundfish Working Group (Anon., 1974, 1975). It has been possible to determine:

(i) the numbers of fish in the sea at various ages (based on VPA with M = 0.2);

(ii) the corresponding weights or biomass of fish in the sea at various ages.

The estimates have been adjusted by linear interpolation to relate to the biomass and numbers of fish at the middle of each calendar year. The estimates have also been restricted to relate only to the numbers and weights of fish $\geqslant$ 2 years of age. In this way only fish that would normally be of marketable size have been included.

For haddock and whiting the results are given in columns A and C of Tables 1 and 2. Table 3, column A, shows the mean numbers of cod in the sea $\geqslant$ 2 years of age. For this species, biomass estimates have not been made.

3. CATCHES (LANDINGS) PER UNIT FISHING EFFORT

Estimates of catches (landings) per unit effort have been made from both commercial and research vessel data. For Scottish trawlers estimates have been obtained of

(i) landings in cwt per 100 hrs fishing for the whole of the northern North Sea. Results for haddock and whiting are given in Tables 1 and 2, column B;

(ii) estimates of the numbers of fish $\geqslant$ 2 years of age landed per 10 hrs fishing by trawlers fishing in the northern North Sea and also off the Scottish east coast. These estimates are shown in Tables 1–3;

(iii) for Scottish research vessels, estimates from Jones and Hislop (in press), have been obtained of the numbers $\geqslant$ 2 years of age caught per 10 hrs fishing.

The values are expressed in "Old Explorer" units.

4. RESULTS

Two sets of comparisons have been made:

(i) Between the weights landed per 100 hrs fishing by Scottish trawlers and the mean biomass in the sea estimated from VPA for haddock and whiting (i.e., a comparison of columns A and B in Tables 1 and 2).

(ii) Between the numbers caught per 10 hrs fishing, and the numbers in the sea. For haddock and whiting this means a comparison of columns D–G with column C in Tables 1 and 2. For cod this means a comparison of columns B–D with column A in Table 3. For this species, research vessel catches in the northern North Sea have tended to be rather small so these have not been included in the study.

Table 1

HADDOCK

Stock size and "catches" per unit effort

YEAR	Weights A	B	C	Numbers D	E	F	G
1959	130	142	297	2480	635	400	1762
1960	124	135	333	2294	1068	800	1817
1961	104	121	266	2364	969	420	1822
1962	138	122	396	1774	442	230	1256
1963	511	116	1672	1931	1340	1950	1701
1964	790	190	2276	3061	2676	8260	2911
1965	667	219	1404	3946	1682	3230	3066
1966	460	277	782	6126	866	1535	4080
1967	327	255	650	3704	836	280	2589
1968	940	207	2974	2269	2338	390	2296
1969	1323	226	3936	2683	3538	15900	3016
1970	750	467	1748	4587	5926	3210	5108
1971	384	472	873	5213	3214	710	4435
1972	382	309	1064	3312	4099	1310	3618
1973	349	230	940	2519	4595	1250	3326

Table 2

WHITING

Stock size and "catches" per unit effort

YEAR	Weights A	B	C	Numbers D	E	F	G
1959	126	36	456	1783	768	533	1388
1960	130	34	505	895	568	1103	767
1961	136	42	528	981	938	932	964
1962	164	44	640	1350	568	860	1046
1963	273	54	1082	2379	839	1489	1780
1964	314	49	1206	1157	1078	9890	1126
1965	278	38	1009	688	984	2034	803
1966	222	40	786	715	1092	1115	862
1967	198	49	714	974	874	320	935
1968	322	56	1250	1415	804	1482	1177
1969	329	47	1270	1440	1058	2917	1291
1970	183	50	650	963	1264	1285	1080
1971	144	54	510	812	1056	368	907
1972	211	50	804	745	761	108	751
1973	388	43	1545	785	991	195	865

A mean biomass during year from VPA (M=0.2) - thousands of tons
B landings per 100 hours fishing by Scottish trawlers (cwt)
C numbers (millions) in the sea ⩾ 2 years from VPA (M=0.2)
D-E numbers ⩾ 2 years landed per 10 hours fishing by Scottish trawlers
D Northern North Sea
E Scottish east coast region
F numbers ⩾ 2 years caught per 10 hours fishing by Scottish research vessels
G weighted mean of Columns D and E

Table 3

COD

Stock size and landings per unit effort in Region IVa
(by numbers only)

YEAR	A	B	C	D
1963	72	115	458	248
1964	63	178	328	236
1965	71	121	223	161
1966	95	178	358	248
1967	98	236	391	296
1968	84	217	263	235
1969	66	229	297	255
1970	58	257	168	222
1971	91	230	226	228
1972	92	465	359	424
1973	58	327	219	285

A mean numbers (millions) in sea $\geq$ 2 years from VPA (M=0.2)
B-D numbers $\geq$ 2 years landed per 10 hours fishing by Scottish trawlers
B Northern North Sea
C Scottish east coast region
D weighted mean of Columns B and C

Table 4

Showing correlation coefficients between various measures of stock abundance

A Abundance estimates based on weights (correlations between biomass of stock and weights landed per unit fishing time)

	Haddock	Whiting
Using numbers	0.25	0.31
Using log numbers	0.51	0.38

B Abundance estimates based on numbers (correlations between number in the stock and numbers landed per unit fishing effort)

	Haddock				Whiting				Cod		
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(4)
Using numbers	-0.08	0.44	0.78	0.20	0.12	0.26	0.37	0.20	0.15	0.44	0.37
Using log numbers	0.15	0.68	0.71	0.46	0.08	0.32	0.28	0.19	0.10	0.49	0.33

Four estimates of catch per unit effort have been used

(1) Numbers per 10 hours fishing by Scottish commercial trawlers fishing in the northern North Sea.
(2) Numbers per 10 hours fishing by Scottish commercial trawlers fishing off the Scottish east coast.
(3) Number per 10 hours fishing by Scottish research vessels.
(4) Using Column G in Tables 1 and 2 and Column D in Table 3.

For each comparison, values have been plotted on double logarithmic paper and some examples are shown in Figures 1 and 2. Figure 1 shows the relationship between the haddock research vessel catches per unit fishing effort, and the numbers in the sea from VPA. Here the relationship between the two stock abundance series is very good. This was in fact the best relationship obtained.

Figure 2 shows the relationship between the whiting landings per 10 hrs fishing by Scottish trawlers fishing in the northern North Sea, and the numbers in the sea. Here the relationship is clearly very poor and the correlation coefficient was in fact found to be non-significant.

Correlation coefficients have been determined for all the comparisons made, and the results are shown in Table 4. For each comparison, correlations were determined using both the numbers in Tables 1-3 and also the logarithms of the numbers.

Table 4A shows the correlations for haddock and whiting between the biomass of the stock and the weights landed per unit fishing time (i.e., correlations between columns A and B in Tables 1 and 2). Four correlation coefficients were calculated and all were non-significant.

Table 4B shows the correlations between the numbers in the stock and the numbers landed per unit fishing effort (i.e., correlations between columns D to G and C in Tables 1 and 2 and columns B to D and A in Table 3). For the three fish species a total of 22 correlation coefficients have been determined. Of these only three were found to be significant. These were:-

(i) The two correlation coefficients between haddock research vessel catches per unit effort, and the numbers in the sea.

(ii) For haddock a significant correlation was also obtained between the numbers in the stock and the numbers landed per unit fishing effort by Scottish vessels fishing off the Scottish east coast, using transformed data. The corresponding coefficient using the untransformed numbers was however not significant.

One other set of comparisons was attempted by plotting various estimates of stock density against time. Some examples are shown in Figures 3 and 4. These show the numbers of fish $\geqslant$ 2 years of age landed per 10 hrs fishing by Scottish trawlers (G). Also shown are the numbers in the sea $\geqslant$ 2 years of age (C). Figure 3 shows the results for haddock and Figure 4 the corresponding results for whiting.

For haddock, the VPA data (Line C) show two peaks of stock abundance. One peak occurred in 1964 due to the appearance at two years of age of the strong 1962 year class. A second peak occurred in 1969 due to the appearance at two years of age of the strong 1967 year class. These two year classes were more abundant than any other year class during the period considered. Estimates of stock abundance based on commercial vessel sampling also showed two peaks of abundance but these were not entirely in phase with the VPA data. The peaks tended to occur rather later when the strong year classes were 3-4 years of age.

A possible explanation for these discrepancies is that the strong year classes were so abundant when young that the market was not able to absorb the whole of the potential supply so that some fish that would normally have been considered of marketable size would have had to be rejected.

Some evidence is available from estimates of discards made on board commercial vessels. In 1969 for example, data were collected from three vessels, and the percentage of haddock rejected was found to range from 16 percent to 71 percent by weight. In two other years when similar observations were made (1965 and 1966) the percentage of haddock

Fig.1 Relationship between haddock research vessel catches per unit effort and numbers in the sea (≥2yrs of age)

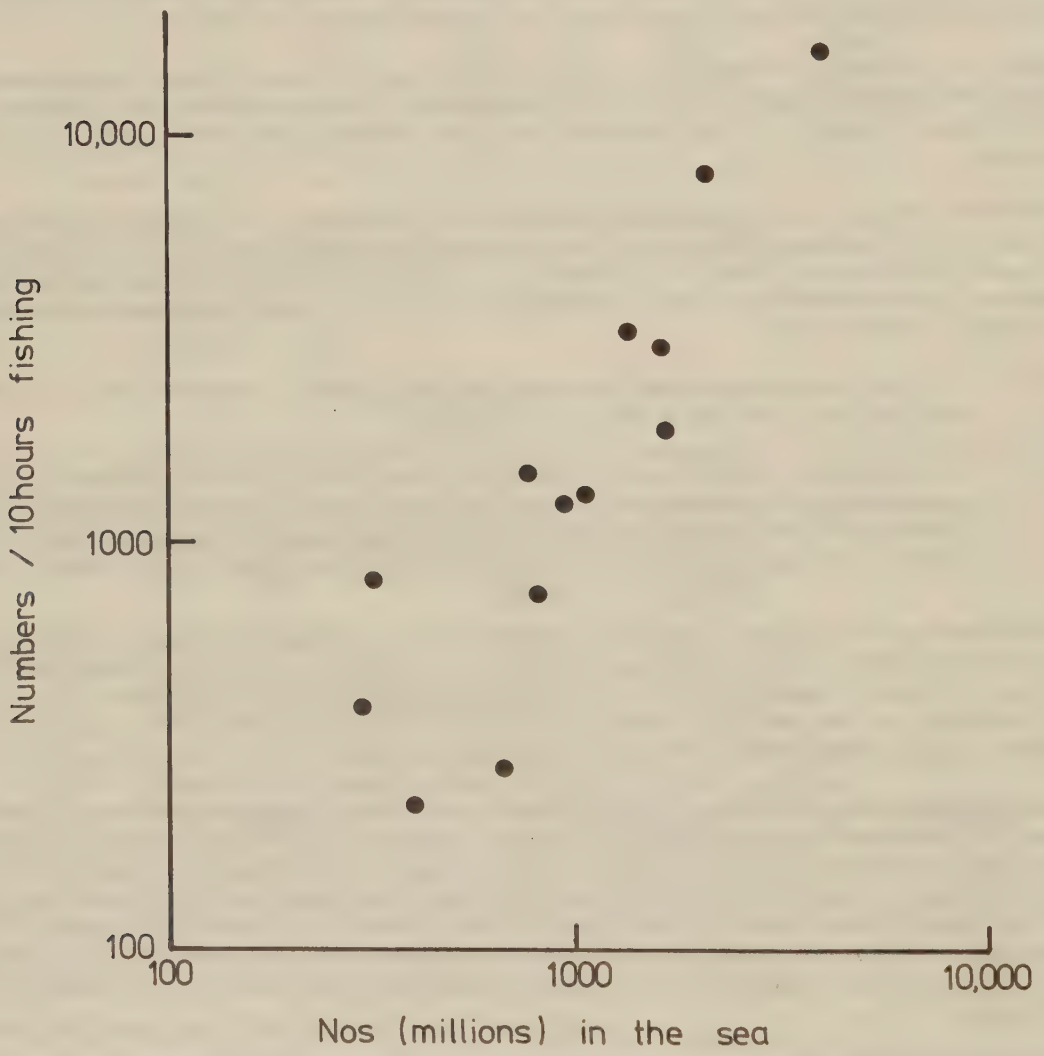


Fig. 2 Relationship between whiting landings per 10 hrs fishing by Scottish trawlers from northern N. Sea and numbers in the sea (≥ 2years of age)

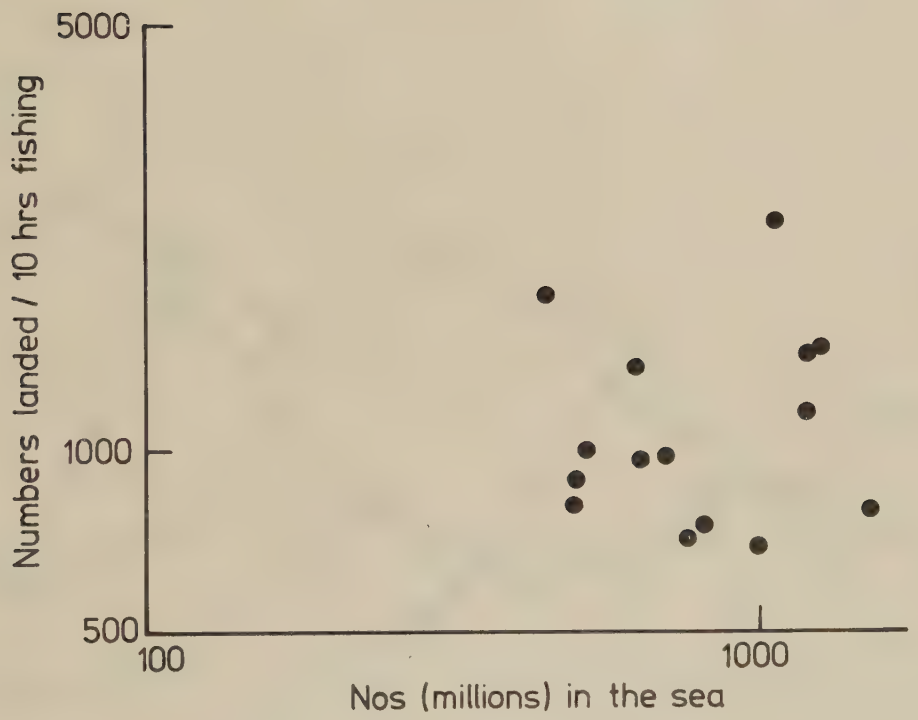


Fig. 3 NUMBERS OF HADDOCK CAUGHT PER 10 HOURS FISHING COMPARED WITH NUMBERS IN THE SEA

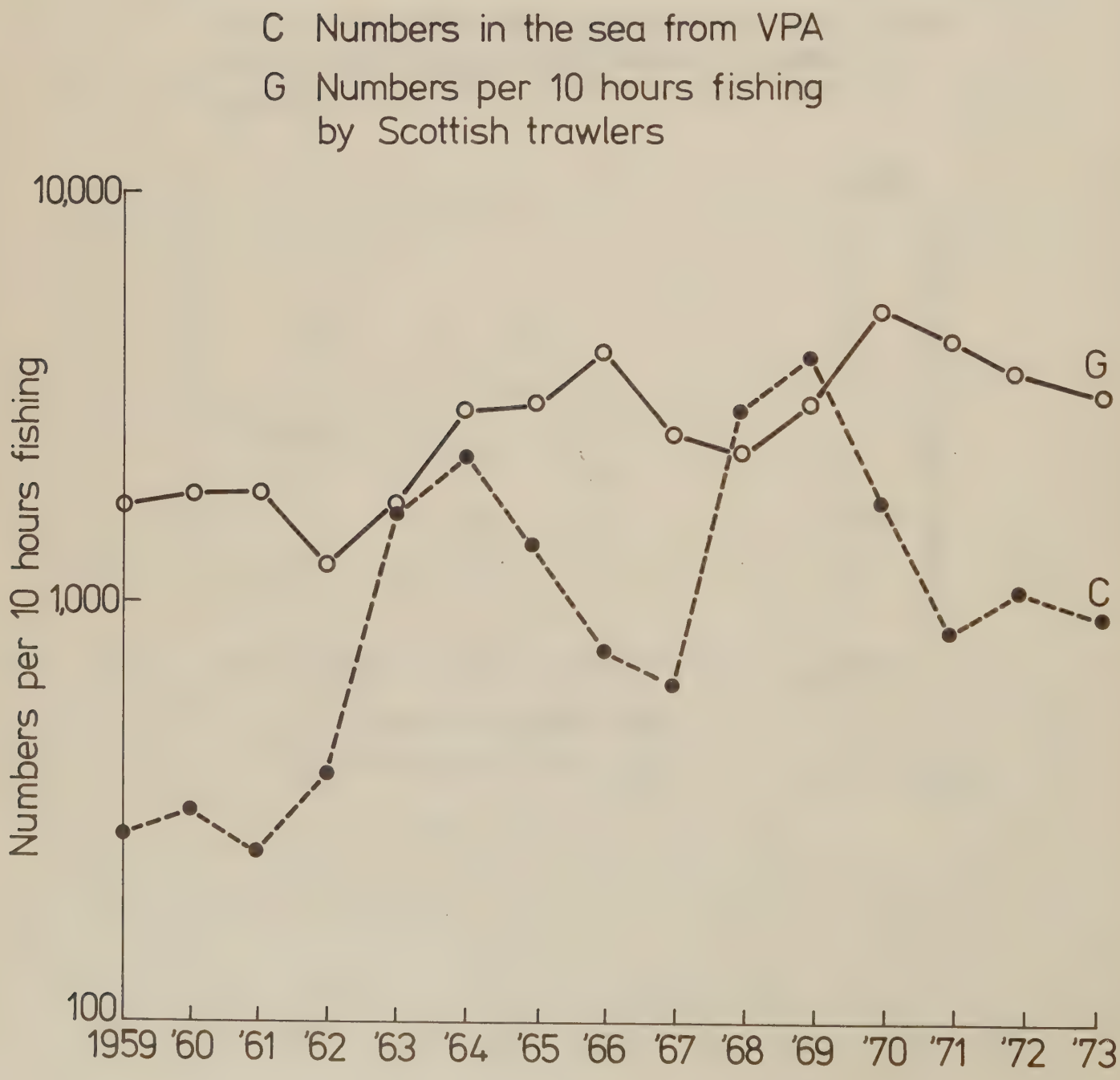
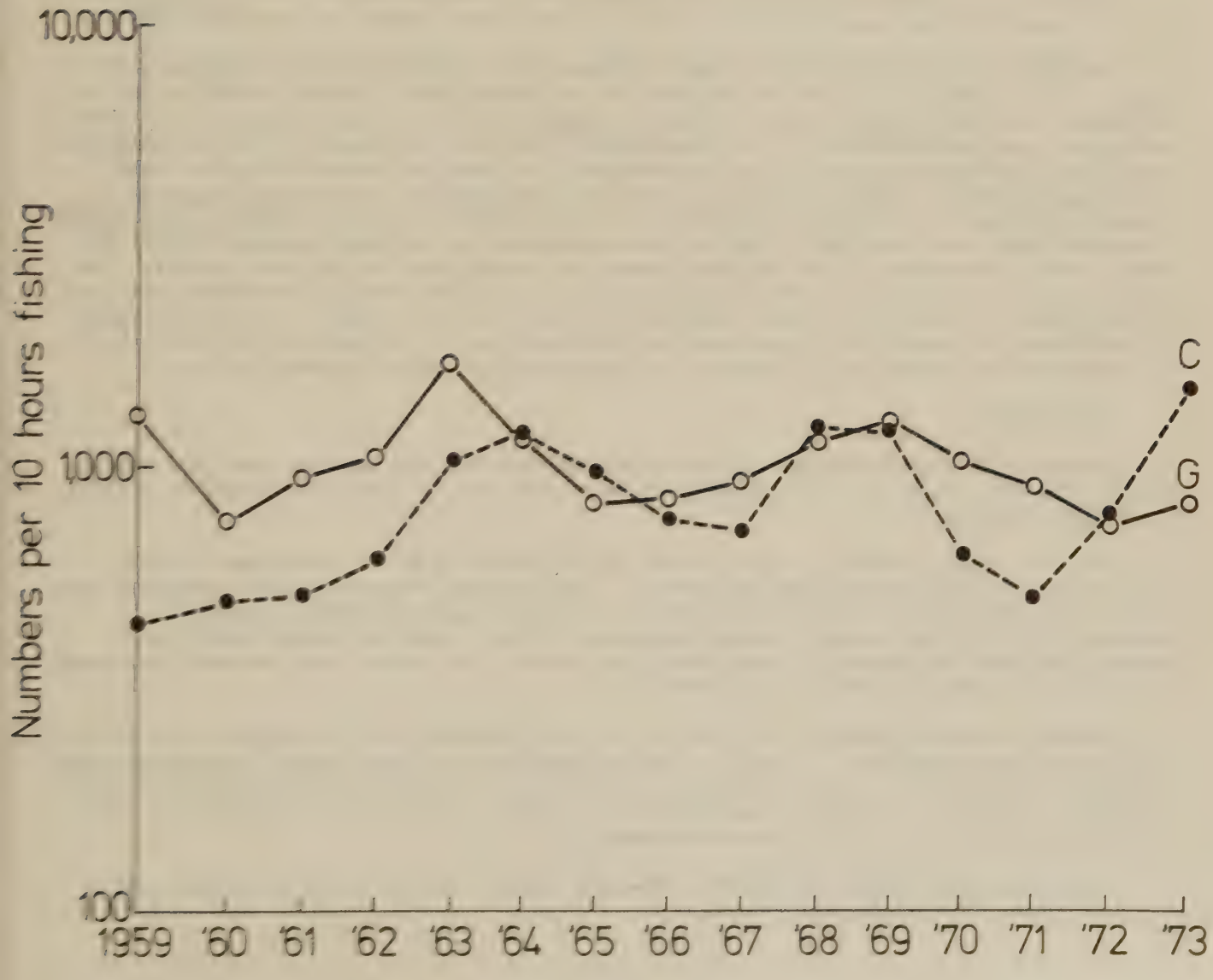

C Numbers in the sea from VPA
G Numbers per 10 hours fishing by Scottish trawlers
10,000
1,000
100
Numbers per 10 hours fishing
G
C
1959 '60 '61 '62 '63 '64 '65 '66 '67 '68 '69 '70 '71 '72 '73

Fig. 4 NUMBERS OF WHITING CAUGHT PER 10 HOURS FISHING COMPARED WITH NUMBERS IN THE SEA

C Numbers in the sea from VPA

G Numbers per 10 hours fishing by Scottish trawlers



rejected was also variable, but ranged from negligible to 33 percent by weight.

An additional factor is that the growth rates of the good year classes of 1962 and 1967 were below average. As a result a larger proportion of 2 year old fish should have been undersized, and hence have qualified for rejection, in 1964 and 1969 than would have been the case in other years.

For whiting the 1962 and 1967 year classes were also strong although not to the same extent as for haddock. They also, however, led to peaks in the VPA estimates of stock size in 1964 and 1969. It is interesting to note in Figure 4 that although commercial vessel estimates of abundance from the two parts of the northern North Sea tended to follow the VPA fluctuations in abundance they also exhibited sufficiently large deviations for the correlation coefficients (Table 4) to be non-significant.

This analysis shows that research vessel catches per unit effort appear to provide a better index of stock abundance than the catches per unit effort by commercial vessel.

5. DISCUSSION

Although it is generally assumed that catch per unit effort ought to be proportional to stock abundance there are a number of factors which could influence this relationship.

Consider, for example, a trawl fishing ground within easy range of a vessel's home port. If the catch per unit effort happened to be greater than a certain level it would presumably be worth fishing there. Otherwise it would not. So long as it was profitable to fish on a particular ground, it is reasonable to suppose that vessels would be attracted there until the catch per unit effort had declined to a level at which no further boats would be attracted. Therefore one could visualize the catch per unit effort as being determined primarily by economic factors, quite independent of stock abundance. The number of vessels that could profitably fish a particular ground would then be determined by the rate at which fish moved in from adjacent areas to replace fish as they were caught. The size of the stock would only affect this process to the extent that it influenced the rate of replacement of fish as they were removed. The implication is that for a certain range of stock density, variations in magnitude might simply lead to changes in the distribution of fishing effort rather than changes in the catch per unit effort on each ground.

6. CONCLUSIONS

Estimates of stock abundance for North Sea haddock, whiting and cod have been made by various methods. These have been correlated with estimates of stock size based on virtual population analysis.

Research vessel catches per unit effort were compared with VPA estimates of stock size for haddock and whiting, but not for cod. For haddock, research vessel estimates were found to correlate well with the estimates of stock size based on virtual population analysis. For whiting, research vessel estimates did not correlate significantly with virtual population estimates of stock size, but tended to be higher than correlations based on commercial vessel catches per unit effort.

Commercial vessel landings per unit effort were compared with VPA estimates of stock size for all three species. To allow as far as possible for discardings, these comparisons were confined to fish $\geqslant$ 2 years of age. In general, it was found that commercial vessel estimates of stock size based on landings per unit effort did not correlate significantly with estimates based on virtual population analysis.

In general, the results showed that research vessels have provided a better index of stock abundance than commercial vessels.

To explain the relatively poor correlation obtained using commercial vessel landings per unit effort it is suggested that commercial catches per unit effort might be influenced by economic factors. There are various possibilities:-

(i) For example, market demand could influence the amount of effort directed at different species.

(ii) The quantities rejected could be influenced by market demand. In particular in 1964 and 1969, when there were relatively very large numbers of the two good haddock year classes in the North Sea, it is probable that many fish of marketable size were rejected.

(iii) The catch per unit effort on a particular ground could be predetermined by economic factors. The rate at which fish moved in from surrounding areas to replace fish as they were caught might then determine the number of boats that a particular ground was able to support. As a result, variations in stock size might lead to changes in the distribution of fishing effort, rather than to simple proportional changes in the average catch per unit effort.

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FUEL CONSUMPTION AS AN INDEX OF FISHING EFFORT FOR SMALL AND MEDIUM RANGE TRAWL FISHERIES, WITH PARTICULAR REFERENCE TO THE MEDITERRANEAN TRAWL FISHERIES

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CONTENTS

		Page
1.	THE PROBLEM	64
2.	PROPOSAL OF A NEW INDEX OF EFFORT	64
3.	CONCLUSIONS AND PERSPECTIVES	68
4.	REFERENCES	68

1. THE PROBLEM

Classic methods of stock assessment, on which sound management should be based, require a certain flow of basic data, which in turn depends very much on the existence and effective work of national institutions dealing with the collection of statistics and on fisheries laboratories.

National statistical offices are usually more concerned with the kinds of data which are relevant from the standpoint of economics. The collection of data on fishing effort suitable for stock assessment use is therefore most often out of their scope.

As stock assessment is a job for fisheries laboratories and considering that, whichever model one intends to apply, effort data is something one cannot do without if stock assessment has to be achieved, it follows that a proper machinery for the collection of such data has to be planned, sooner or later, either by fisheries laboratories directly or through national statistical offices. This would require some time before a satisfactory stage of efficiency is reached.

Because it is most common that the development of fisheries takes place at a quicker rate than the development of the systems for monitoring them, first assessments have often to be made based on historical data, in fact with any kind of historical data which can possibly substitute for the preferred ones, which are often not available.

Thus, instead of unavailable data on detailed fishing effort, e.g., number of hauls or hours fishing, it is common practice to look for and make use of data on fleet strength (e.g., number of boats, total GRT, etc.), usually as yearly totals. They have the advantage of being the kind of data which national statistical offices are likely to collect routinely, but may not be proper measures of fishing effort for the following reasons:

(i) They could only be a measure of the "maximum potential fishing power" of fleets. This will give an index of the actual fishing effort exerted during a year provided a simple relationship (direct proportionality at the best) is demonstrated or can reasonably be assumed between, say, number of boats or their GRT, and the fishing effort of fleets. In practice it will not be known how much of the potential fishing power has actually been employed, neither is it known how much time has actually been spent fishing.

(ii) They give no information about the location of fishing operations. This may be critical for short and medium range trawl fisheries, where some crude assumptions such as that bigger trawlers fish exclusively on certain distant grounds cannot be reasonably put forward. It is common that small and medium size trawlers registered in one port move to another port, may be far away, and start fishing from there. When that occurs, it would be completely misleading to consider a fleet's "maximum potential fishing power" as expended close to the registration port.

(iii) Data on fleet strength are seldom broken down by kind of fishing. This raises a major problem in the case of multi-purpose vessels, converting from demersal to pelagic fishing according to the season or (worse) to market demand.

2. PROPOSAL OF A NEW INDEX OF EFFORT

The situation described above applies well to most Mediterranean trawl fisheries, and has been of great concern to the GFCM Working Party on Resources Appraisal and Exploitation ever since it was created.

In that context, and following recommendations of that Working Party, another category of substitute data was found to evaluate effort, which can be as easily available as the ones listed above, but seems to be free from most of their drawbacks and limitations. This is the consumption of gas oil.

As an elementary form of economical incentive, many governments exempt fishermen from paying (wholly or partly) taxes on gas oil. Some kind of routine control has then to be kept on its delivery, to avoid either reselling by fishermen or adulteration by dealers (e.g., to car diesel oil) or any other kind of improper use. Sometimes fuel is even given a distinctive colour, and is classified as "fuel for fishermen".

Records of the controls may be available under various forms. The most fortunate case occurs when each vessel is given a document (e.g., a booklet) where all fuelling operations must be recorded. Customs officers in a port may sometimes directly note the quantities of gas oil delivered there to each fishing vessel, but elsewhere they may only check record books kept by dealers. All these various arrangements (and may be others) may occur together. In some countries the administration offices in charge of the control may even publish statistical bulletins, where information on fuel consumption is provided with some time, place, etc., breakdown. However, from the various source documents, one should be able to collect information on how much fuel, where and when it has been delivered.

(i) How much fuel has been delivered to the boats, either individually or to a certain portion of the fleet (according to the kind of available source documents), during a certain time. Fuel consumption is commonly reported in text books of ship engineering as being proportional to [engine power x its time of motion], and consumption data therefore seems suitable for use as an index of fishing effort, i.e., of [fishing power x time spent fishing]. In doing so, one has to make some assumptions on both factors of the product.

(a) The simplest is that there is a direct proportional relationship between fishing power and engine power. Beverton and Holt (1957) showed such a relationship for a number of trawlers fishing from Lowestoft and Grimsby on the southern North Sea grounds in 1946-1947. Noetzel and Norton (1969) showed a similar relationship between daily fuel costs (therefore fuel consumption) and power of the main engine for Boston large trawlers. But if one wants to apply fuel consumption as an index of fishing effort, there is strictly no need to assume such relationship, provided a similar one can be demonstrated between catches of trawlers, fishing on about the same densities of fish but belonging to different engine power categories, and their total fuel consumption for the same period.

(b) The aforesaid demonstration would also prove the validity of another assumption, i.e., that total fuel consumption can be satisfactorily used instead of the quantities of fuel consumed by the main engine alone, which are not known. Apart from any quantitative study, for most short and medium range fisheries it can safely be assumed that auxiliary engines make up a small part indeed of total fuel consumption.

(c) A trawler does not actually consume fuel for fishing only, but during steaming and other dead time as well. Thus, the double nature of the time component inherent to the data of fuel consumption may discourage their use as indices of fishing effort. This problem (somehow linked to the one cited under (b) above) may be irrelevant provided at least one of the following two conditions occur:

- time spent fishing is much longer than steaming time (i.e., a fleet staying many days on about the same grounds, or a fleet fishing very close to the base port).

- the ratio (fuel consumed for fishing): (total fuel consumed) does not change markedly during the time series used for the stock assessment.

An Italian trawl fishery of the Middle Adriatic sea was taken as a case study to check the assumption (a) above; based on direct knowledge of the fishery, assumptions listed above under (b) and (c) were thought to be reasonable (Levi and Giannetti, 1973).

For 28 trawlers registered in the port of Ancona but landing in four ports (and fuelling in two of them) thereabout, the total catches in weight for two years were plotted against the total fuel consumption of each vessel during the same period (Fig.1).

A straight line was drawn through the points, with a rather good fit ($r = 0.92$), thus checking assumption (a), which shows that, for practical purposes fuel consumption can be used as a measure of fishing effort for the fishery taken into consideration.

(ii) Where (i.e., in which port) the trawlers filled up their tanks with fuel. For most small and medium scale trawl fisheries, one can safely assume that the vessels tend to fill up their tanks in their actual base port, which, in turn, will usually face their actual fishing grounds. (However, that can be checked by simple surveys). Hence, it seems fair to correlate landings in a port with fuel consumption recorded for the same port (or larger statistical area), which amounts to a rough way of locating fishing operations.

(iii) When the fuel was consumed. This information is very often available with greatest detail (date of each fuelling operation). Although this may involve a great deal of work (which can be cut down by ADP) by making use of some other independent information, the analysis of individual source documents would allow time spent fishing by other methods than trawling to be omitted from the compilations, however irregular and unpredictable the change of method may be. Such independent information can be provided by auction bills (usually compiled for each vessel, thus reporting vessel name) where the species composition of the landings reflects the kind of fishing.

When the demersal fishery of the Adriatic Sea referred to above was studied, the account books of the Fishermen's Cooperative of Ancona (reporting summaries of fish sales) were found to show a "½" mark against the boats which were temporarily fishing by semi-pelagic trawl, to indicate that earnings had to be shared among the two paired vessels towing the gear together.

However the supplementary information is collected, once the days spent fishing by other methods than trawling are identified, it is then possible to substract the data of fuel consumption falling into the same periods.

Sometimes, individual and daily source documents are not available, but summary data of fuel consumption exist for longer periods and for a number of vessels together.

If the change of method is known to occur with a rather regular periodicity, and if the time detail of the summaries is small enough in comparison with the periods devoted to the different fishing methods, these data are just as good and of quicker use than the more detailed ones.

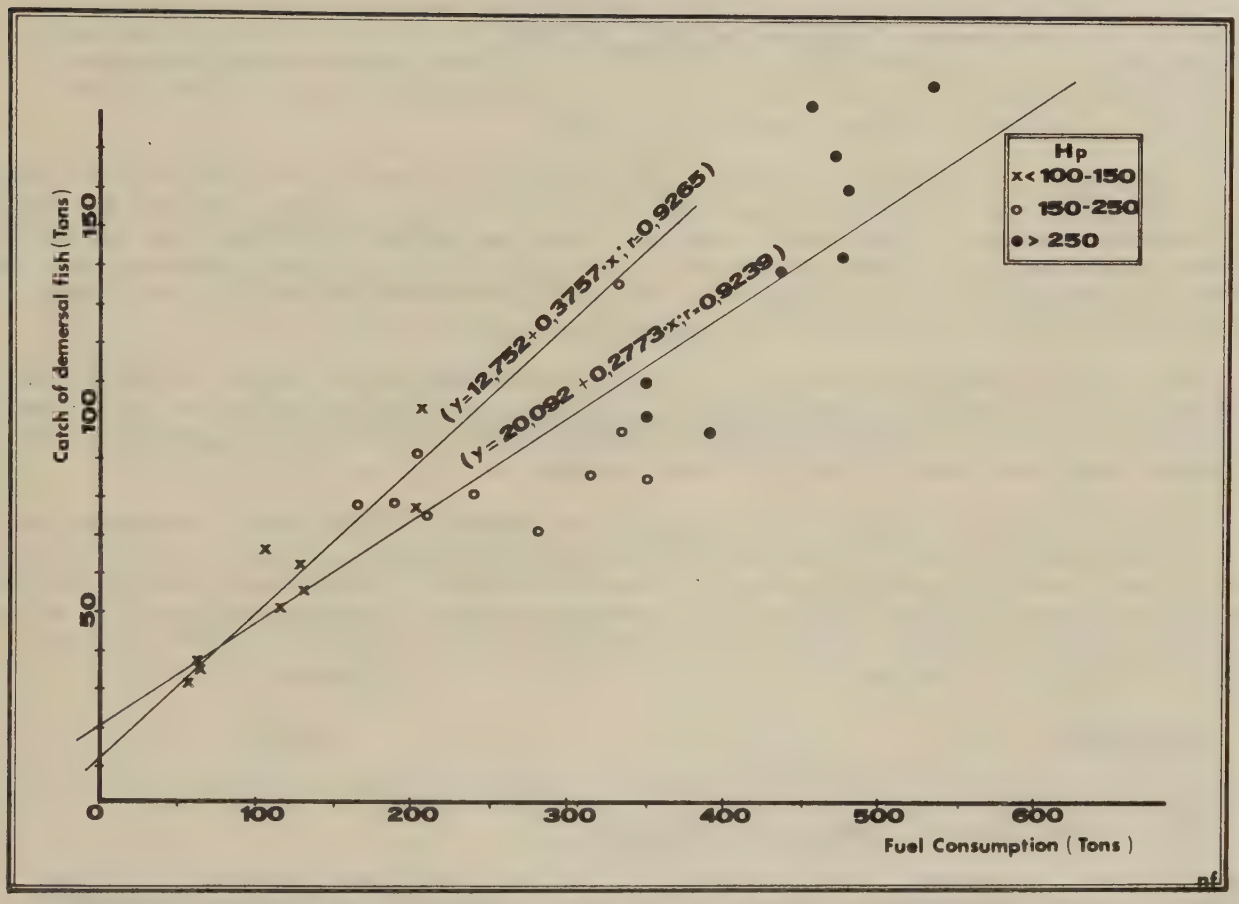

Fig.1 Relationship between total demersal catches by individual vessels and corresponding fuel consumption during the years 1970–1971

3. CONCLUSIONS AND PERSPECTIVES

It has been suggested that data of fuel consumption may be usefully treated as a measure of fishing effort to study the history of some trawl fisheries, provided careful check of the occurrence of some conditions is maintained, taking into account the knowledge both of the limitations of this index of effort and of the characteristics of the fishery itself. [In fact, data of fuel consumption have already been used successfully as a measure of fishing effort to appraise the hake stock of the Adriatic Sea (Levi and Giannetti, 1973)].

Such index of effort seems to be more suitable for short and medium range trawl fisheries, for the reasons explained before. In fact, the regression line drawn only through the points representing boats below 150 HP, almost passed through the origin (Fig.1, intersect = 12,752 tons), i.e., the relation approaches closer to exact proportionality for boats fishing closer to the land.

It may also prove convenient to adopt permanently the data of fuel consumption as an index of fishing effort (with the same limiting conditions, of course) for both economical and practical reasons. Sometimes it may be cheaper and quicker to spend time and money in the improvement of a machinery for data collection which has already been set up by an official administrative body, rather than starting a different and totally new system, which could also run into difficulties of its own.

Many fishery scientists know how difficult and frustrating it may be to try to have fishermen fill up log books. Full coverage of the activity of a fleet is not often easily obtainable in this way. This may seriously hamper proper monitoring of changes in stock abundance when total catch is not well known either.

On the other hand, because of the reasons for which it is recorded, information on fuel consumption is likely to come from the whole of the fleet. It may therefore be more productive to persuade administrators to record additional information on fishing methods and fishing location as part of the job of recording data of fuel consumption. In this way some major limitations of its use as an index of fishing effort could be eliminated while retaining its advantages.

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DERIVATION OF CATCH PER UNIT OF EFFORT FROM COMMERCIAL FISHING STATISTICS FOR THE BERING SEA, 1964-73

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CONTENTS

		Page
1.	INTRODUCTION	70
2.	FISHING EFFORT ANALYSIS	70
	2.1 Source and adequacy of data	70
	2.2 Effort related to species	72
	2.3 Catchability coefficient adjustments	72
3.	CATCH PER UNIT OF EFFORT	73
	3.1 Target species	74
	3.2 Non-target species	82
4.	DISCUSSION AND CONCLUSION	82
5.	REFERENCES	83
6.	NOTES	84

ABSTRACT

Japanese commercial catch-effort data are the most detailed and complete, in temporal and areal sequence, of all data sources for determining catch per unit effort (CPUE) indices of abundance of demersal fish stocks in the Bering Sea. To assess any stock using this index however, the data have to be screened and selected since the fishery is multi-species and multi-gear in nature. The most difficult problems are (1) analysis of fishing effort to determine the proper levels of fishing effort attributed to catch the particular stock under consideration, and (2) subsequent adjustments to the selected effort values to take account of changes in the fishing power of the vessels concerned - mainly through advancing technology and improved fishermen skills. In this paper, derivations of CPUE from four studies on walleye (Alaska) pollock, Theragra chalcogramma, currently the primary target species of the fishery, are used to illustrate the procedures used to assess trends in the fishery and the fish stocks. As the species diminish in overall importance from occasional target to incidental species, the problem of determining the effort for that species in a multi-species fishery becomes more difficult. Although the problems of CPUE analyses in the Bering Sea involving multiple species are very similar to those encountered elsewhere in the world, the solutions will depend on the species mix and the data base.

1. INTRODUCTION

In a typical fishing operation, an input of fishing effort results in an output of catch. These two fundamental input-output quantities - catch and fishing effort - then provide the basic information used for assessing the fishery. In order to use the catch per unit of fishing effort (CPUE) as a true reflection of the abundance of stocks exploited, the effective amount of fishing effort has to be determined. Unfortunately, most of the problems associated with the use of fishing effort information, especially that of commercial fisheries as pointed out in ICES (1954) and Gulland (1956), are difficult to solve. Some of the difficulties arise as the species mix of exploited fish stocks changes in space and time. Likewise, fishing patterns directed to catch these stocks also tend to change.

In the Bering Sea, commercial catch-effort information constitutes the most complete set of data available for studying the demersal fisheries. Although these fundamental input-output data may not be adequate to describe all the details of the fishery, it is still possible to describe the general trends in the fishery and fish stocks. The most difficult problem in fishing effort analyses is to determine appropriate measures of fishing effort to be attributed to catches of certain stocks. Such a determination is complicated in the Bering Sea by the multi-species and multi-gear structure of the fishery.

The emphasis in this paper is on determination of fishing effort directed toward catch of certain individual species and adjustments to catchability coefficients needed for measuring effective fishing effort. The resulting information on effort will then be used with catch information to evaluate the status of demersal fish stocks in the Bering Sea. The determination of a catch per unit of effort (CPUE) index of stock abundance for the walleye (Alaska) pollock, Theragra chalcogramma, will be used to illustrate analysis of CPUE for demersal stocks in the Bering Sea.

2. FISHING EFFORT ANALYSIS

2.1 Source and adequacy of data

Japan, through the International North Pacific Fisheries Commission (INPFC), provides most of the available statistics on demersal fisheries in the Bering Sea. Also available are limited commercial catch and effort statistics of non-INPFC member nations (Republic of Korea and the Soviet Union) which participate in the fisheries on a fairly wide scale. However, of all data sources, the commercial catch-effort data from Japan are the most complete for fisheries analyses. Supplementary biological statistics such as size and age information are also collected for important species in research cruises by Japan and the United States, and by U.S. scientists placed aboard Japanese commercial fishing vessels.

The major developments of demersal fisheries in the Bering Sea took place after the second world war. Since 1954, Japan and the Soviet Union (since 1958) mounted such intensive fisheries that by 1964, a number of stocks had already been over-harvested (Pruter 1973). For example, the eastern Bering Sea yellowfin sole, Limanda aspera, ceased to be the major objective of the trawl fishery after about 1963, and this stock has not yet recovered, the catch remaining far below the 1961 peak of 600 thousand metric tons (MT) (Fig. 1).

The period 1954-63 can be considered the first of two phases of the postwar fishery, with yellowfin sole the principal species harvested. Unfortunately, systematic detailed statistics from the fisheries were not collected until late 1963; thus much of the early history of the resource is not available. As a result, the original conditions of some of the stocks (yellowfin sole; sablefish, Anoplopoma fimbria; and Pacific ocean perch, Sebastes alutus) cannot be traced because data are inadequate.

During the second phase (1964-73), the total catch of demersal fish increased from the earlier phase peak of about 600 thousand MT in 1961 to another of 2.2 million MT in 1972 (Fig. 1), with pollock as the principal species caught. Unlike the earlier phase, systematic

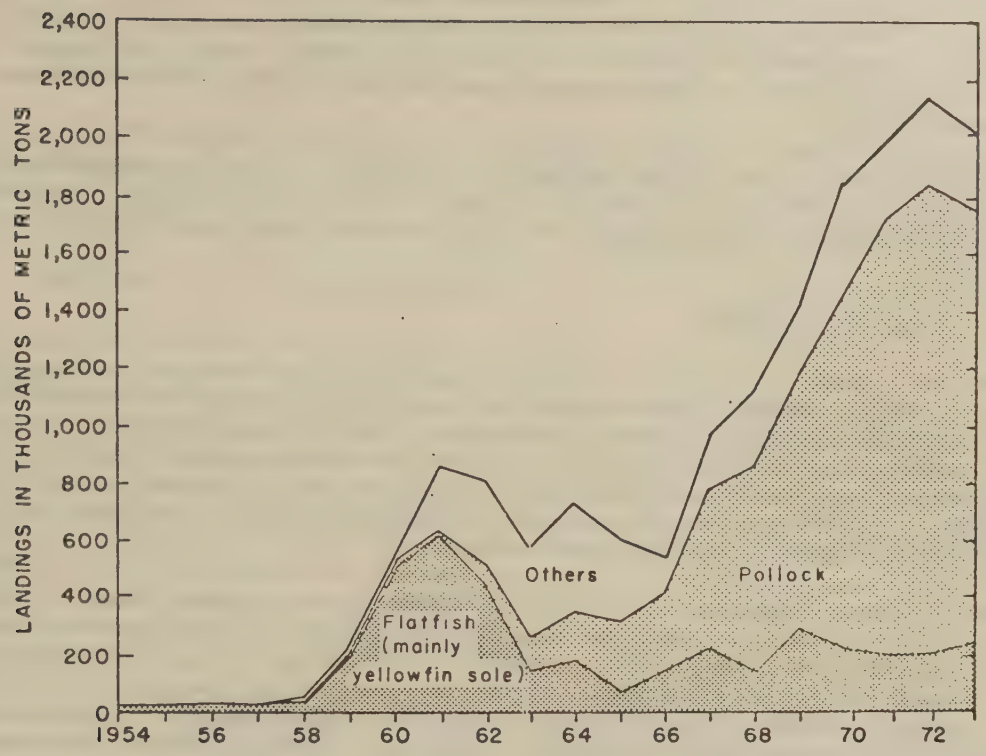

Figure 1. Estimated landings of flatfish, pollock, and other bottomfish by all nations from the Bering Sea, 1954-73.

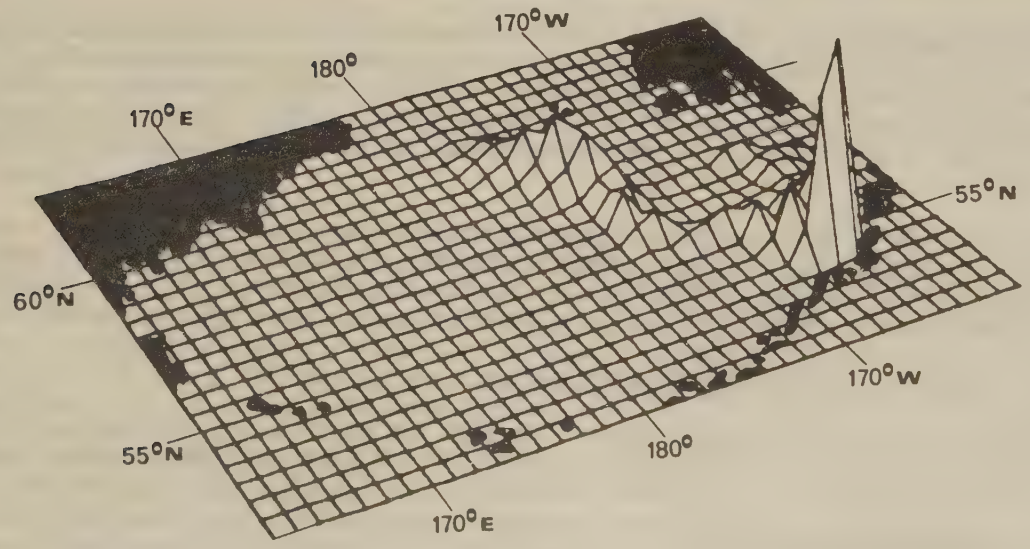

Figure 2. Example of a three-dimensional graph depicting fish caught by area, time and gear-vessel type in the Bering Sea.

detailed statistics during this phase of the fishery have been kept, notably by Japan. The Japanese commercial fisheries data dealing with catch and effort are given by year, month, gear type, degree of longitude, half-degree of latitude, species catch, and (since 1968) by vessel size category. Therefore, the status of some exploited stocks could at least be inferred from such statistics.

One will have to assume that catch estimates are correct. This may not always be the case, especially when the amount of 'discards' at sea is not accounted for. The problem of discards at sea is probably less serious after 1967 when uses were found for all the fish caught (Pruter 1973).

2.2 Effort related to species

Since there is a great diversity of species caught with each unit of fishing gear, CPUE analyses may proceed according to a single species, a multi-species or a pooled species approach. In the single species approach, determination of fishing effort and hence CPUE of stocks are treated in turn as though each is a single species system. In further analysis it is usual to assume that there is no species interaction, and to ignore competition and predation. There is little that can be done about including interaction terms because so little is known about demersal community interactions.

If interaction terms could be quantified, a multi-species approach could be taken whereby each species is treated as part of an intricate ecosystem. The problem of determining effective effort (and an appropriate measure of CPUE) for a single species in a multi-species fishery should be distinguished from the problem of using catch-effort data referring to a single species in the analysis of the events in a region in which several species occur, and can be expected to interact. Whereas the first is mainly an estimation problem, the second is mainly analytical. In Bering Sea demersal fish communities, both single species and multi-species analyses are warranted according to species but the latter approach has not been taken for lack of knowledge on species interaction.

However, one may treat the species complex as a whole and determine empirically the relation between total effort and all-species catch as though in a single-species situation (Gulland 1972). The advantage of this pooled-species approach is that it is simple and will probably include some effects of species interactions.

Whichever approach is used, it is still necessary to partition recorded nominal fishing effort into (1) effort directed to catch a certain species or group of species (f_D) and (2) other effort that is not directed to catch this species (or species group)(f_{ND}). Species-directed nominal fishing effort can then be used in the simple catch equation of $C = q\ f_D\ \bar{B}$ where C is catch, q is the catchability coefficient of f_D, and $\bar{B}$ is the average stock biomass.

From this basic catch equation and assuming that q is known or constant, inferences may then be made regarding the status of the exploited stock. However, q is affected by many factors which have to be taken into account when data from different areas or time periods are compared. Adjustments of q will be covered in the next section.

2.3 Catchability coefficient adjustments

Associated with each gear type, the catchability coefficient, defined as the ratio of fish caught to the stock available for a given unit of fishing effort (Ricker 1958), changes with time and place. It is a function of several important factors such as:

(i) Random haul variations

(ii) Weather and geographic conditions

(iii) Cyclical (seasonal or diel) variations of fish distribution

(iv) Density of fish on fishing ground

(v) Behaviour of fish with respect to fishing gear

(vi) Skill of fishermen, especially of skippers to select good fishing grounds and fish schools

(vii) Distribution of fishing fleet in time with respect to that of fish

(viii) Power and size of fishing vessels

(ix) Type and size of fishing gear

Large random haul-to-haul variations will be reduced when thousands of separate fish operation data are combined. Variations due to weather will also be reduced when data are averaged over a period of time. Variations due to seasonal and diel movements of fish are most likely to be reduced when data are compared for certain periods of the year in similar locations and, if necessary, for certain times of the day. Behavioural responses with respect to the fishing gear are usually difficult to account for. The responses are probably size dependent as fish distribute themselves by size in time and space. Herding or avoidance effects could be influenced by the density of fish in the path of the fishing gear. For lack of more accurate information, they are usually assumed to be unity for trawl sweeps for most bottom species.

Variations due to the ability of fishermen to select good fishing grounds, detect fish schools and move fishing vessels in a timely manner are very important in the fisheries. Since the vessels operate in fleets with good daily communications between vessels from the same company, it is assumed that information of more productive fishing grounds is circulated and these areas are fished heavily. As fish detection and communication systems improve each year, q must also increase with time. Also, the abilities of the fishermen probably improve. All these human factors are difficult to quantify but some form of a learning curve may be appropriate for adjusting q from year to year.

Much of the variation in q is the result of changes in fishing gear, fishing techniques and vessels which may be parameterized. Gulland (1956) calculated fishing powers of different gear-vessel types to adjust fishing effort to a standard. With the use of high speed computers, it is possible to adjust fishing effort according to the fishing powers of individual vessels and gear throughout the season. However, in most commercial operations catch-effort data associated with individual vessels are proprietary in nature and are usually summarized. The finest level of data identification is therefore usually to gear and vessel size.

Though it is not possible to account for all the major sources of variation in q, it is possible to reduce some of the variability if fishing effort information for a certain species is considered for particular time periods and areas. Such selected fishing effort units may then be adjusted for changes in fishing power due to such factors as technological improvements. In addition to much technological change in the Bering Sea demersal fisheries, the experience and skill of fishermen have rapidly improved, and these two factors - technology and learning - are of primary importance in q.

3. CATCH PER UNIT OF EFFORT

The concept of catch per unit of effort as a measure of stock abundance is well documented in such papers as Ricker (1958), Beverton and Holt (1957), and Gulland (1969). Some case studies of CPUE for some demersal fish species, especially the target species of pollock, yellowfin sole, ocean perch, and sablefish are presented here. Applications of CPUEs, catch, and total standardized effort units in stock size, yield, and recruitment derivations (using techniques which are quite standard in population dynamics) are not included in this paper.

3.1 Target species

3.1.1 Pollock

Pollock make up about 85 percent of total demersal fish harvest and in certain areas and seasons it is the target species of the Japanese mothership mince-meat fleet and the North Pacific stern trawl fleet. Associated with mothership fleets are catcher boats operating Danish seines, side trawls and pair trawls for pollock in the continental shelf region. Each of these gear types is usually directed to catch pollock principally in certain areas. Therefore, by selecting data belonging to certain gear-vessel types in certain areas and times, the fishing effort exerted to catch pollock may be extracted from the summarized data base.

With the use of three-dimensional computer graphics for displaying pollock catch by area, time, and gear-vessel type (Fig. 2, Low 1974) (see note 1, page 84), the selection of time and area groupings for computing indices of abundance may be quickly determined, for example, pair trawl catch and effort in the shelf region. The pair trawlers have contributed increasingly to the pollock catch since 1964 (Table 1) as a result of increasing effort. Effort and catch by certain other gear types, such as Danish seiners and side trawlers, have decreased.

Pair trawl has been selected by Alton and Fredin (see note 2, page 84) and by Takahashi (see note 3, page 84) as a gear type that best determines pollock abundance particularly if the effects of increasing fishing power due to horsepower changes of the vessels are taken into account. Their assumption that q is related to horsepower of the vessel is supported by Maeda (1972) who reported that catch per hour trawling by pair trawlers increases proportionately with brake horsepower.

Alton and Fredin (see note 2) summarized their analysis by six large areas (Fig. 3) used by INPFC in recommending conservation measures for Pacific halibut, Hippoglossus stenolepis, for annual periods. The annual effort data, in hours, were multiplied by the annual mean vessel horsepower. Catch per thousand pair trawl-horsepower-hours were computed and the total fishing effort was estimated by dividing the all-nation pollock catch by pair trawl CPUE.

Takahashi (see note 3) refined the annual data to areas of 1° longitude by $\frac{1}{2}^{\circ}$ latitude blocks which is the finest areal division possible. Using pair trawl effort, Takahashi computed average density indices (ADI) of pollock as

$$ADI = \frac{1}{n} \sum_{i=1}^{n} d_i$$

according to Doi et al. (1972) where d_i = CPUE, or density index, in the i^{th} 1° longitude by $\frac{1}{2}^{\circ}$ latitude statistical block. The annual average index was then adjusted by an annual modulation factor related to Maeda's (1972) fishing power factor (Table 2) calculated from vessel brake horsepower data. But since the fishery is dynamic and fishes on different components of the stock in different years, this procedure of weighting CPUE by the number of statistical blocks actually fished will tend to distort true stock abundance trends.

Low (1974) selected stern trawl fishing effort to compute CPUE for pollock because it is also a target species off the continental slope. Since the fishing power of stern trawls has not increased very much over the years, adjustments to q need be considered for fishermen skill only. Instead of computing CPUE of a gear type and total effort by dividing total catch with CPUE of the gear type, total catch is divided by total standardized effort on a monthly basis. To compute monthly total standardized fishing effort, effort of each gear type is standardized and summed over area. The fishing effort of each gear type in each 1° longitude by $\frac{1}{2}^{\circ}$ latitude statistical block relative to a certain standard gear type (stern trawl class 8 vessel) is computed by

Table 1

Catch of walleye pollock by gear type in the Japanese mothership and North Pacific trawl fisheries in the Bering Sea, 1964-73

Gear type	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Danish seine	138 492	176 453	129 526	253 971	326 319	353 107	445 588	362 425	312 959	228 306
Pair trawl	33 790	44 321	60 852	137 481	167 600	153 980	367 811	485 604	635 950	538 379
Side trawl	2 525	5 553	66 643	51 319	11 428	14 845	4 622	-	-	-
Stern trawl	514	1 430	6 979	103 506	161 838	319 048	384 873	634 101	700 151	725 579
Others	2	-	-	-	-	-	-	-	-	-
Total catch	175 520	227 973	264 757	548 487	671 303	841 774	1 203 247	1 491 409	1 649 565	1 492 263

Data source: Takahashi (see text note 3)

Table 2

Average density index (ADI) of abundance of walleye pollock in the Bering Sea, 1964-73 (after Takahashi, see text note 3)

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Fishing power by Maeda (1972)	8.44	8.44	9.34	9.86	12.74	15.90	16.98	20.10	20.80	-
Modulation factor	.66	.66	.73	.77	1.00*	1.25	1.35	1.58	1.63	1.74**
ADI	5.65	6.13	5.00	6.37	11.84	12.99	11.99	9.13	15.24	10.87
Adjusted ADI by modulation factor	8.53	9.25	6.83	8.23	11.84	10.41	9.00	5.79	9.33	6.25

* 1968 vessels chosen as standard

** Estimated by Takahashi (1974)

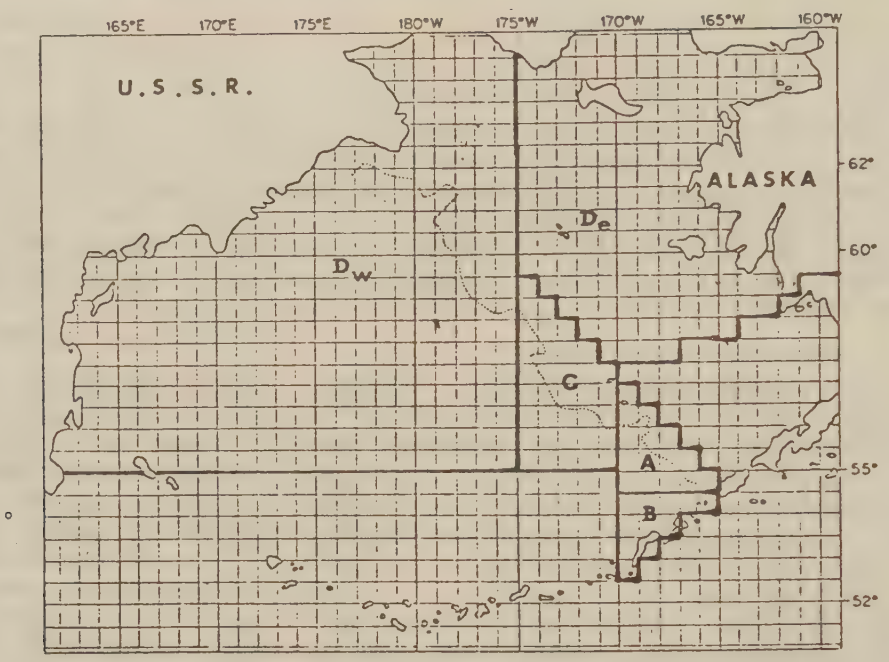

Figure 3. Map of locations of Bering Sea areas partitioned by the following scientists for analysis of fishing effort on pollock: (a) Alton and Fredin (see text note 2) into areas A to D, (b) Takahashi (see text note 3) and Low (1974) into degree longitude by half degree latitude blocks, and (c) Chang (1974) into areas east and west of 170°W longitude.

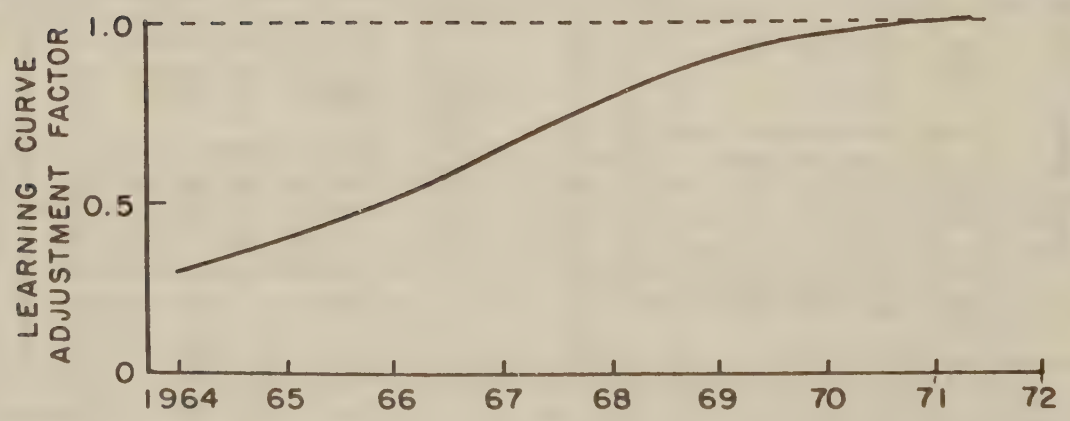

Figure 4. A theoretical learning curve depicting fishing power increase with time for the Bering Sea, 1964-72.

$$f_{sjk} = P_{ijk} f_{ijk}$$

where f_{sjk} = fishing effort standardized to selected standard gear-vessel class (s) in year j in statistical block k

P_{ijk} = fishing power relative to selected standard gear-vessel class for gear-vessel class i, year j, and statistical block k

f_{ijk} = nominal fishing effort for gear-vessel type i, year j, and statistical block k.

Relative fishing powers are computed using a computerized version of Robson's (1966) maximum-likelihood technique of estimating relative fishing power of individual vessels. The total amount of fishing effort is merely the sum of all standardized fishing effort. Then, a monthly overall index of pollock abundance in the entire Bering Sea area is computed by dividing total catch with total standardized effort. The alternative mean of ratio estimator of

$$\text{CPUE} = \frac{1}{n} \sum_{i=1}^{n} (c/f)_i$$

is not used after testing the variance of catch against effort (Low 1974). A weighted linear regression test shows that the variance of catch is proportional to effort rather than to the square of the effort.

From monthly CPUE (derived for every month of the year 1964 through 1971), the month of each year when the population biomass in the Bering Sea area during that year is estimated to be highest is selected to indicate annual CPUE abundance for pollock. This criterion is used because the fishery does not operate in the same areas in the same month from year to year and the comparison of CPUEs should be made between periods when the stock is most available for capture during each year. It is assumed that the stock is most available for capture when the absolute biomass (calculated from CPUE data, taking account of the number of statistical blocks actually fished) is highest. Otherwise, when the stock is less available, the fishery does not operate as extensively over the range of the stock.

Each computed annual CPUE index is later adjusted according to an assumed learning curve (Fig. 4) representing the effects of fishermen skill on q. Because q for the standard stern trawl class 8 vessel is changed very little by technology (Takahashi 1974), such an adjustment according to skill may reflect most of the increase in effective effort. Alton and Fredin (note 2) and Takahashi (note 3) adjusted effort according to horsepower increases, but improvements in trawl design, material, and fish detection electronics were not considered. Experience must also have improved fishing strategy and efficiency. Although these factors are deemed necessary to adjust for q, their quantification by a learning curve is extremely difficult and debatable.

All the three procedures of selecting effort attempted to pick data that best represent pollock abundance. Chang (1974) attempted to partition nominal fishing effort to get effective fishing effort by a correlation method. In this procedure, three species (pollock, ocean perch, and yellowfin sole) are considered dominant in four gear types (pair trawl, side trawl, stern trawl, and Danish seine). In a given area and month, let

y_1 = pollock catch

y_2 = ocean perch catch

y_3 = yellowfin sole catch

f_1 = pair trawl effort

f_2 = Danish seine effort

f_3 = side trawl effort

f_4 = stern trawl effort

It is assumed that catches, y, and efforts, f, are normally distributed. Partial correlations are computed between y_k and f_m ($k = 1, 2, 3$; $m = 1, 2, 3, 4$) while fixing the effects of other gear type efforts $f_{m'}$, ($m' \neq m$; $m = 1, 2, 3, 4$). For instance, $\rho y_i f_2(f_1, f_3, f_4)$ is the measure of interdependence between pollock catch and Danish seine effort while the efforts of pair, side and stern trawls are held constant. That is, the coefficient is expressed as the variability of pollock catch and Danish seine effort when the other gear type efforts are constant. The symbols $\rho y_1 f_2(f_1, f_3, f_4)$ can be expressed as $\rho 12(1, 3, 4)$ and similarly, for others we have as subscripts.

Gear	Species		
	Walleye pollock	Pacific ocean perch	Yellowfin sole
Pair trawl	11(2,3,4)	21(2,3,4)	31(2,3,4)
Danish seine	12(1,3,4)	22(1,3,4)	32(1,3,4)
Side trawl	13(1,2,4)	23(1,2,4)	33(1,2,4)
Stern trawl	14(1,2,3)	24(1,2,3)	34(1,2,4)

The coefficients are interpreted as the vulnerability or gear efficiency coefficient for the k^{th} species by the m^{th} gear type in a given area and time. Effective fishing effort is then calculated by the following relation:

$$f'_{ijkm} = \rho_{ijkm} \, f_{ijm}$$

where f'_{ijkm} = total effective effort in the i^{th} area and j^{th} period for the k^{th} species by the m^{th} gear type;

ρ_{ijkm} = gear efficiency coefficient by area, period, and species;

f_{ijm} = total nominal effort by area, period and gear.

Table 3 summarizes the differences in the procedures used by Alton and Fredin (note 2), Takahashi (note 3), Chang (1974), and Low (1974). Results of the CPUE analysis according to the four procedures are shown in Table 4 and Figure 5. It is not unusual that fishing effort analyses have been approached from the standpoint of easy computation because the data base is too large for easy handling. Though it is difficult to select the most accurate procedure, it can be generally accepted that the pollock data should be selected according to fine time and area divisions such as month and statistical block for analyses of stock abundance.

3.1.2 Other species

Pollock is such an abundant species in the Bering Sea that the fishery can be viewed as a single species system if the areas are carefully delineated. However, for other species that are occasional targets in the demersal fisheries, the selection of certain areas and

Table 3

Procedures of analysis of fishing effort on walleye pollock that have been used by different scientists

Procedures	Scientists			
	Takahashi[1]	Alton and Fredin[2]	Low 1974	Chang 1974
Multi-national data source				
Selected Japanese data	*	*	*	*
Adjust analysis to catch by all nations	X	*	*	X
Multi-species				
Single species analysis	*	*	*	*
Pooled species analysis	X	X	*	X
Data stratification				
1. By area				
Summed over 5 large areas	X	*	X	X
Summed over 2 large areas	X	X	X	*
Summed over more than 80 statistical blocks of 1° longitude by ½° latitude	*	X	*	X
2. By time periods				
Annual scale	*	*	X	*
Monthly scale	X	X	*	X
Fishing effort analysis				
1. Effort by species				
Selected representative gear	*	*	*	X
Partitioned effort of gear	X	X	X	*
2. Catchability coefficient adjustment				
With vessel horsepower	*	*	*	X
With a learning curve	X	X	*	X
3. Total effort				
Total catch by all nations	*	*	X	X
Sum of (effort x relative fishing power)	X	X	*	*

* Procedure followed

X Procedure not followed

1/ See text note 3

2/ See text note 2

Table 4

Values of relative abundance - of the Bering Sea stock of pollock - that have been estimated by different scientists using different procedures

Source	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Takahashi[1/]	8.53	9.25	6.83	8.23	11.84	10.41	9.00	5.79	9.33	6.25
Alton and Fredin[2/]	9.52	18.34	24.04	21.73	24.00	31.78	18.78	15.24	14.50	
Low (1974b)[3/]	6.46	8.48	4.74	6.67	6.50	7.28	5.73	5.99		
Chang (1974)[4/]	2.72	4.80	4.40	7.09	7.67	7.79	13.10			

1/ See text note 3; tons per modulated pair trawl hour

2/ See text note 2; tons per thousand pair trawl-horsepower hours

3/ Tons per adjusted stern trawl hour

4/ Tons per effective pair trawl hour

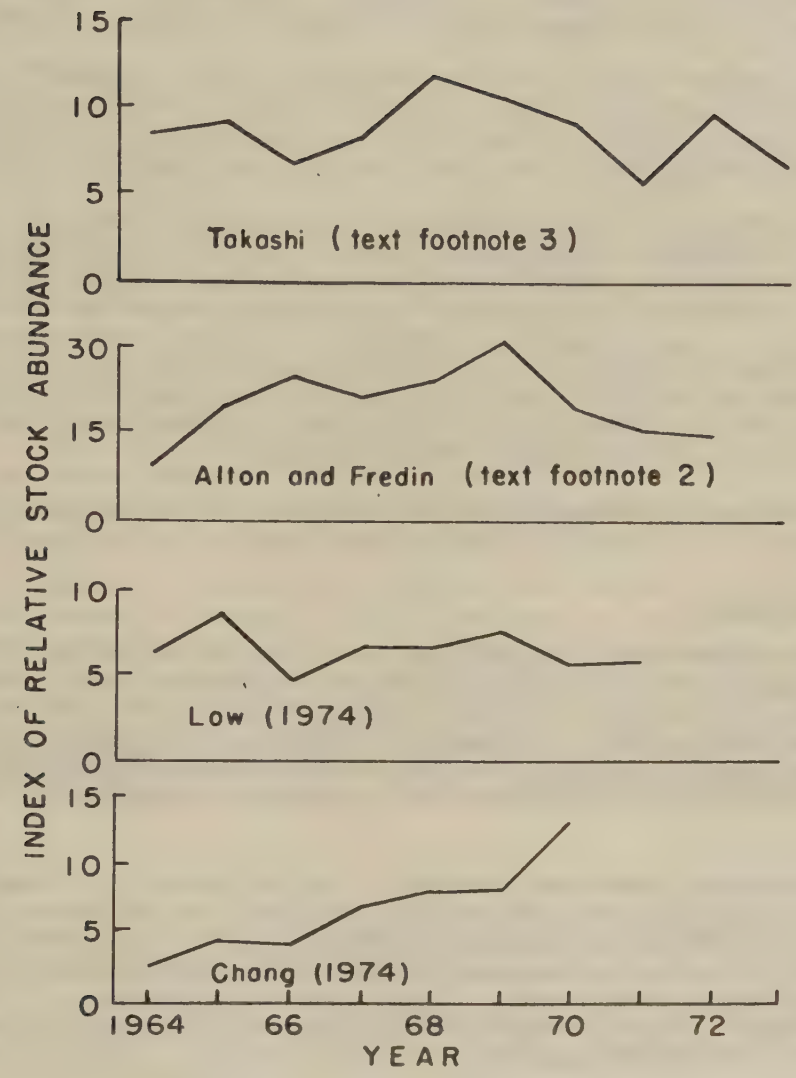

Figure 5. Curves showing annual relative abundance — of the Bering Sea stock of pollock -- that have been estimated by different scientists using different procedures.

gear-vessel types that will best gauge stock abundance is more difficult and less accurate. The yellowfin sole, Pacific ocean perch, and sablefish are each target species in some areas: the yellowfin sole by pair trawls in the eastern Bering Sea flats (towards the Alaska mainland) and the other two species by longline and stern trawlers off the Aleutian Islands and the outer continental slope.

Following the procedure of excluding data which fall below an arbitrary percentile level (Ketchen 1964), catch-effort data in 1° longitude by ½° latitude statistical blocks where yellowfin sole make up 50 percent or more of the total catch by pair trawls in the eastern Bering Sea flats can be grouped for analysis. The data can further be grouped by fishing season according to the spring-summer and winter fisheries for yellowfin sole.

Low (see note 4) analysed longline data for sablefish in the Aleutian region for the second quarter (April to June) of the year when most of the sablefish are caught for the year in the region. Chikuni (1971) and Low (1974) selected stern trawl fishing data to compute relative stock abundance for ocean perch, also in the Aleutian region.

In the estimation of CPUE for these occasional target species, only data from certain index areas and time periods have been used to indicate relative stock abundance. There are other areas and time periods when these species are caught incidentally to pollock in considerable amounts. The yellowfin sole are also caught in the outer continental shelf areas where pollock predominate. Large amounts of sablefish and ocean perch are caught by stern trawlers off the continental slope where pollock also predominate. In the Aleutian CPUE index area, ocean perch are landed by longliners as well as by large stern trawlers. All these fish caught in non-index areas and periods by non-index gear types are important yet have to be left out in determining relative stock abundance.

As the species becomes less abundant and less important in the multi-species fisheries, an appropriate gear-time-area index for CPUE analysis becomes more difficult to find.

3.2 Non-target species

Many of the minor species make up less than one percent of the overall catch on the average. For such species where no definable areas or time periods can be singled out year after year as specific fishing areas for these species, there is no simple way for selecting index areas and gear-vessel types. For example, the rock sole, Lepidopsetta bilineata; flathead sole, Hippoglossoides elassodon; and arrowtooth flounder, Atheresthes stomias, seldom are target species and are relatively low in abundance where the main fishery operates.

Since these flatfish are incidentally caught in the yellowfin sole fishery, it may be true that CPUE of any gear type effective for flatfish and directed toward yellowfin sole may be representative of the species abundance. However, until more is known about the distribution of these minor species and their mixing with yellowfin sole, it is difficult to comment on their relative stock status. Also, since the abundance is so low in the overall catch, the single species concept of CPUE is probably less applicable. Consequently, the pooled species approach may be applied.

The pooled species approach lacks individual species detail and though the single species method of CPUE analysis is questionable when applied to species groups, it gives a relative idea of abundance. The data are usually screened to eliminate effort with zero catch and CPUE is determined simply by dividing total catch by effort. When interpreting CPUE indices for these minor species, possible changes in the pattern of fishing as the effort is devoted to catch one or other of the major species should be kept in mind.

4. DISCUSSION AND CONCLUSION

Catch per unit of effort (CPUE) derivation is the first step in many subsequent population dynamics analyses. The catch-effort data may be used to estimate maximum sustainable yield from generalized surplus production models (Schaefer 1957; Pella and Tomlinson 1969).

Together with age-length data, the relative strength of year classes may be derived. Mortality rates may be determined and with weight data, yield per recruit analysis (Beverton and Holt 1957) may then be conducted. These are some of the analyses that have been carried out for the Alaska pollock fishery.

It is important that the fundamental statistics on catch and effort be accurate and consistent for comparison by area and time. Catch is measured in a standard unit of measurement and is usually assumed to be accurately reported by area. On the other hand, effort has no standard unit of measurement. The effective level of effort directed to a certain species is changed by a number of factors that cannot be parameterized. The four procedures used to analyze data on effort for pollock are by no means a complete set of alternatives and can be improved upon. To achieve the best result, the commercial catch-effort data base should be screened carefully to eliminate data by gear, time, and area where a certain species is definitely not found. It is practical to aggregate data to 1^{o} longitude by $\frac{1}{2}^{o}$ latitude statistical blocks by month and gear type. As much as possible, factors that change the catchability coefficient such as technological changes and learning should be taken into account, and the figures of nominal fishing effort adjusted accordingly. In general, CPUE indices are appropriate for measuring stock abundance of major target species if done correctly. However there is no proper procedure, but only convenient ones, to derive CPUE of minor species in the Bering Sea multi-species fishery.

Interactions between species are important in the demersal community, but the community is such a complex system that simplification to a single-species or a pooled species method of analysis is the only practical alternative. It is, however, possible to postulate species interactions in a fish ecosystem model to study the dynamics of the stocks. Such a model may not answer specific questions important to management but should direct research priorities with a better perspective of the Bering Sea system and a more informed interpretation of CPUE data.

Finally the problems of determining relative stock density in the Bering Sea mutliple species situation are very similar to those encountered in the Atlantic and elsewhere. Although the Bering Sea CPUE exercises, like those in other fisheries, may not have anything new to contribute to stock assessments done since the 1950s, they nevertheless illustrate the importance of standardizing fishing effort and the most practical means of gauging stock size trends. The fishing power expended by the fishery simply cannot be assumed constant from year to year as the fishing processes mature with time. One must pay special attention to technological improvements and fishermen skills occurring especially in well organized fishing fleets.

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DATA REQUIREMENTS FOR OBTAINING LESS BIASED CATCH PER UNIT EFFORT FOR ATLANTIC TUNAS

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CONTENTS

		Page
1.	ATLANTIC TUNA DATA PRESENTLY AVAILABLE	86
	1.1 Catch and effort and biological data	86
	1.2 Indices of abundance presently used	86
2.	POSSIBLE CAUSES OF BIAS AND DATA REQUIRED TO CORRECT IT	86
	2.1 Inadequacy of data	86
	2.2 Multi-species fisheries	86
	2.3 Multi-country fisheries	88
	2.4 Multi-gear fisheries	88
	2.5 Inter-oceanic nature of fleets	89
	2.6 Fishery management	89
	2.7 Improvement in fishing efficiency	89
	2.8 Bias due to ecology of the fish	89
	2.9 Currentness of data for monitoring populations	89
3.	IMPROVEMENTS REQUIRED FOR OBTAINING LESS BIASED CATCH PER UNIT EFFORT	90

1. ATLANTIC TUNA DATA PRESENTLY AVAILABLE

At the present time, population studies by the International Commission for the Conservation of Atlantic Tunas (ICCAT) are concentrated on the following species:

Yellowfin (Thunnus albacares), albacore (T. alalunga), bluefin tuna (T. thynnus thynnus), southern bluefin tuna (T. maccoyii) and skipjack (Katsuwonus pelamis).

The discussion on tunas contained in this paper refers to the above-mentioned species.

1.1 Catch and effort and biological data

Table 1 summarizes data now available for major tuna fisheries.

1.2 Indices of abundance presently used

For surface fisheries, catch (in metric tons) per "day of fishing" is generally considered to best represent abundance. Otherwise, catch per "days at sea" would be the second choice. "Day of fishing" should, of course, include days spent searching without any catch or sets being made. For longline fisheries, "catch (in number of fish) per 100 hooks used" is the most common.

2. POSSIBLE CAUSES OF BIAS AND DATA REQUIRED TO CORRECT IT

2.1 Inadequacy of data

As can be seen in the table, the only catch/effort data which can be used for monitoring changes in population abundance are: French and U.S. data for tropical surface fisheries; French, and to a lesser degree Spanish, data for temperate surface fisheries; and Japanese data for longline fisheries. These roughly account for 30 percent of bluefin tuna, 50 percent of yellowfin, 60 percent of albacore, 50 percent of bigeye and 60 percent of skipjack.

If there is uniformity among the fishing fleets, the data from the above mentioned coverage could satisfactorily represent the geographical distribution, abundance, etc. of the populations. The following sections will explain, however, why using c.p.u.e. derived from such limited coverage would provide biased estimates of population abundance.

2.2 Multi-species fisheries

Though tuna fisheries are considered to be highly multi-species, less species are involved in surface fisheries than in longline. For example, in temperate waters there are trolling and baitboat fisheries for albacore, which are considered as single species tuna fisheries although there is the occasional catch of bluefin tuna. However, the same boats also go for anchovy, sardine, herring, mackerel, etc. and therefore the total effort applied to the albacore fishery varies greatly from year to year and from season to season, depending on the fishing conditions and the market price of fish, including species other than tunas. Logically, the amount of total effort should not influence the c.p.u.e. value, whereas, in actual fact, it does. The explanation of this is given in Section 2.8.

A more difficult case is that of surface fisheries (purse seine and baitboat) for tropical tunas. Generally these fisheries catch yellowfin and skipjack. On many occasions, two species are mixed together in a catch taken by one set, but more frequently a fish school is made up of one species and, to a certain extent, fishermen can select the species they wish to catch.

Table 1

Type of Fishery	Country	Catch	Effort	Area	Period	Coverage	Biological data	Area	Period	Coverage
SURFACE (Tropical)										
Baitboats	France[1/]	weight	days fishing	1°x1°	monthly	90%	size freq.	general areas	monthly	good
	Japan	weight	days fishing	no break-down	yearly	100%	size freq.	general areas	monthly	poor
	Spain	weight	days fishing	no break-down	yearly	40%	nil			
Purse seine	France[1/]	weight	days fishing	1°x1°	monthly	90-100%	size freq.	general areas	monthly	good
	Japan	weight	days fishing	1°x1°	monthly	90-100%	nil			
	Spain	weight	days fishing	1°x1°	monthly	20%	nil			
	U.S.A.	weight	days fishing	1°x1°	monthly	95%	size freq.	5°x5°	monthly	good
SURFACE (Temperate)										
Baitboats and Trolling	France	weight	days fishing	1°x1°	monthly	90%	size freq.	general areas	monthly	good
	Spain	weight	days fishing	1°x1°	monthly	60%	size freq.	general areas	monthly	good
LONGLINE	Japan	no. of fish	no. of hooks	5°x5°	monthly	80-90%	size freq.	general areas	quarterly	good
	Korea	nil					nil			
	Taiwan	no. of fish	no. of hooks	5°x5°	quarterly	10-20%	nil			

1/ Including Senegal and Ivory Coast

Yellowfin tuna have a higher commercial value and are greatly sought after by the fishermen, unless there are other factors which would limit the catch, e.g., fishing regulations in force, or control of mercury limits in the tuna meat which are acceptable to canneries. Assuming that the fishermen always look for yellowfin first, then the c.p.u.e. as far as yellowfin is concerned can reflect, more or less, the abundance of that species. However, the c.p.u.e. for skipjack can be quite biased, depending on the availability of yellowfin to the fishermen.

In a recent study by I-ATTC, a trial was made at modifying the c.p.u.e. for skipjack, mainly separating fishing grounds for the major areas of yellowfin and skipjack.

In the ICCAT area, not much study has been made on adjusting c.p.u.e. for skipjack. One of the reasons is that Atlantic surface fisheries are less selective towards yellowfin than those of the Pacific.

There are more problems in the case of longline fisheries in which at least nine major species are fished simultaneously. However, even though the geographical distributions of several species overlap, there are indications of some separation in the space they occupy, according to their depth.

For example, bigeye and yellowfin are distributed in the same area and period, but the former are at a greater depth than the latter. Since bigeye are preferred by the Japanese longliners, they set a line deeper to selectively catch bigeye. In such a case, some adjustments can be made to the c.p.u.e. of the lesser preferred species, in the same way as described for surface fisheries. On the other hand, for Korean fisheries, bigeye and yellowfin bring in almost the same market price and the fishing boats therefore set their lines either to the yellowfin or the bigeye depth, whichever species is more abundant in the area.

Correction of biases in such an instance is rather difficult. The unmodified c.p.u.e. for the more abundant species would be over-estimated while that for the less abundant species would under-estimate the real abundance.

2.3 Multi-country fisheries

Tuna fisheries are international since many countries fish for the same species in the same areas, using gears of identical specifications. In addition to the difference in species preference, one can assume that the fishing efficiency may vary in different countries depending on the experience of the fishermen, the wage system used, labour conditions, etc. As a result, the c.p.u.e. applicable to a fleet of one country is not necessarily applicable to a similar fleet of another country.

One good example is, again, the longline fishery. Here we have catch and effort data for all the Japanese fleet, which account for about one-third of the total Atlantic longline tuna catches. Since the other two-thirds are caught by Taiwanese and Korean boats, but no effort data are available for these fleets, we have to take the Japanese c.p.u.e. to represent the other longline fleets as well. Because of the reasons discussed above, the validity of such extrapolation is doubtful.

2.4 Multi-gear fisheries

As has been noted in the previous discussion, tuna fisheries are conducted with several major types of gears, namely, longline, baitboat, purse seine, trolling and traps. The inter-relationship of the populations fished by these gears is quite complicated and our analysis has still not reached a point of clarifying this.

It is obvious that surface gears such as baitboat, purse seine and trolling fish more or less the same population(s), except that purse seiners have greater mobility and a longer range of operation. Therefore the relationship between baitboat and purse seiner

efficiencies can be analyzed by comparing c.p.u.e.'s for the same area and period, for the same species.

On the other hand, we do not know yet whether or not longliners fish for the same population or the same fraction of the population as the surface fishery vessels. A considerable difference is demonstrated in the size frequencies of catches of the two gears and careful studies are required on c.p.u.e., taking into account biological data.

2.5 Inter-oceanic nature of fleets

Tuna vessels are highly mobile, with a long range of crusing. There is a tendency that good fishing conditions in one ocean will draw more fleets to that area, thereby reducing the amount of effort in other areas.

2.6 Fishery management

Any fishery management which limits the amount of catch or size of fish caught, etc. will cause a bias in c.p.u.e. Such a regulation is already in practice for yellowfin tuna in the eastern Pacific and Atlantic Oceans.

2.7 Improvement in fishing efficiency

Tuna boats have been getting larger, faster, more mechanized and, on the whole, more efficient. It is difficult to evaluate the change in the efficiency of a boat. Comparison of the c.p.u.e.'s of older and newer boats fishing in the same area and period may give some indication of changes in efficiency, but the experience acquired by fishermen in the past is not to be taken into account.

2.8 Bias due to ecology of the fish

For some unknown reason, we are experiencing that c.p.u.e. is quite biased in itself. For example, when extensive efforts are applied by longliners in one area, c.p.u.e. seems to decline at a much greater rate than that of the reduction in the actual population abundance as estimated from records of fish finders, catches by other types of gears and/or predictions by population models, etc.

There has been discussion on the causes of this. It has been said that fish learn to avoid the baited hooks, while another theory is that a reduction in the population results in less competition for natural food, and fish are less attracted by the bait on the hooks. Actually, these are still hypotheses and much study is still needed.

In surface fisheries, when populations are reduced we observe the tendency of tuna to continue forming large schools, but fewer of them, rather than reduce the size of the school. This will result in boats of higher speed and more efficient gears suffering less from a population reduction than vessels with smaller cruising ranges and less efficient gears. Catch per unit effort of such modern boats would demonstrate less the decline in population abundance while catch per effort for the smaller, less efficient boats would exaggerate the decline.

2.9 Currentness of data for monitoring populations

Generally, population analysis of Atlantic tunas is delayed by one to one and a half years because of the time lag in reporting catch effort data. Establishing a reporting system for current catch/effort data will be particularly important when fishing regulations such as quota systems, or limitation of effort, are considered and/or introduced.

3. IMPROVEMENTS REQUIRED FOR OBTAINING LESS BIASED CATCH PER UNIT EFFORT

Studies to monitor tuna populations in the Atlantic using c.p.u.e. are not yet sufficiently advanced to require sophisticated correction of minor biases; but still we have to eliminate major biases introduced by the inadequacy of data. The first major improvement expected is to extend coverage of catch and effort data to all major types of tuna fisheries, in every country.

Only when this is achieved can the second step be taken, that is, to compare c.p.u.e. between gears, nations, old and new vessels, etc. in order to see the difference in efficiencies. The third step is to study tuna ecology and biology in terms of fractions of populations taken by the various gears, and examine the availability and catchability, etc. Only then can we plan further improvements in data collection to eliminate more sophisticated biases expected in catch/effort data.

CATCH PER UNIT OF EFFORT IN THE NORWEGIAN PURSE SEINE FISHERY FOR ATLANTO-SCANDIAN (NORWEGIAN SPRING SPAWNING) HERRING

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CONTENTS

		Page
1.	INTRODUCTION	92
2.	THE YOUNG HERRING FISHERIES	92
3.	THE FISHERY ON ADULT HERRING	94
4.	CONCLUSION	97
5.	REFERENCES	101

1. INTRODUCTION

Paloheimo and Dickie (1964) concluded that "when there is heterogenity in fish distributions, catch per unit effort cannot provide a measure of abundance change unless additional information on the distribution of fish and the operations of fishing vessels is available". Their conclusion seems to have special relevance to purse seine fisheries for schooling pelagic species.

The catch per unit time at sea in a purse seine fishery will mainly depend on

(a) searching time to find the fish concentrations;

(b) density of the concentrations found.

The searching time will depend on fish distribution, acoustic equipment, experience of the skippers and communication between vessels. In many purse seine fisheries, as for example the Norwegian fishery for capelin in the Barents Sea, it has been observed that if the fleet has found concentrations of fish it may be able to follow them for a long period. If the density of the concentrations does not decrease significantly with decreasing stock size (a decrease only in the area of distribution), or if the catch per unit fishing operation does not change significantly, it is difficult to see how catch and effort data can give you any information at all about abundance however detailed the measure of effort. It is the author's feeling that in fisheries like the Norwegian purse seine fisheries for herring, mackerel and capelin catch per unit of effort probably would give little information about abundance even if detailed data on effort (e.g., searching time, fishing time, size of net, size of vessel, etc.) were available. It is, however, difficult to prove this because such detailed data have not been collected. It is also generally difficult to analyse more crude measures of catch per unit effort (e.g., catch per boat per day or week or season) due to complicating factors arising from national regulations of the fisheries and periodically stops in the fisheries caused by limited producing capacity on land.

In this paper data from the Norwegian purse seine fishery on Norwegian spring spawning herring in the 1950's and early 1960's are analysed in order to get a rough idea of the relation between abundance and catch per unit effort in this fishery. Fishing mortalities and stock sizes in the period studied have been estimated by cohort analysis by Dragesund and Ulltang (1975). Good measures of abundance should therefore be available. The effort data does not, however, allow a detailed analysis of catch per unit of effort.

2. THE YOUNG HERRING FISHERIES

Cohort analysis (Dragesund and Ulltang, 1975) shows a clear relation between fishing mortality and year class strength in the young herring fisheries.

In Fig.1 is plotted the logarithm of the sum of the fishing mortalities on 0- and 1-group ($F_0 + F_1$) against logarithm of initial year class strength as 0- group (N_0) for year classes 1950-1960. In Fig.2 is plotted for the same year classes the logarithm of the fishing mortality on 2 year-old herring against the logarithm of the number of 2 year-old herring at the beginning of the year. The youngest age groups are to a great extent separated in area. The 0- group and most of the 1- group herring are taken in the "small herring" fisheries and most of the 2-4 year-old herring are taken in the "fat herring" fisheries. Figs.1-2 indicate a linear relationship between ln F and ln N, or in $F = \ln a - b \ln N$, i.e.

$$F = a \cdot N^{-b} \qquad (1)$$

The exponent b is in both cases estimated to be slightly below 1 (0.84 and 0.74 in Fig.1 and Fig.2 respectively). If the fishing effort in the period studied was approximately constant, F will be proportional to the catchability coefficient q ($F = q \cdot f$ where f is fishing effort).

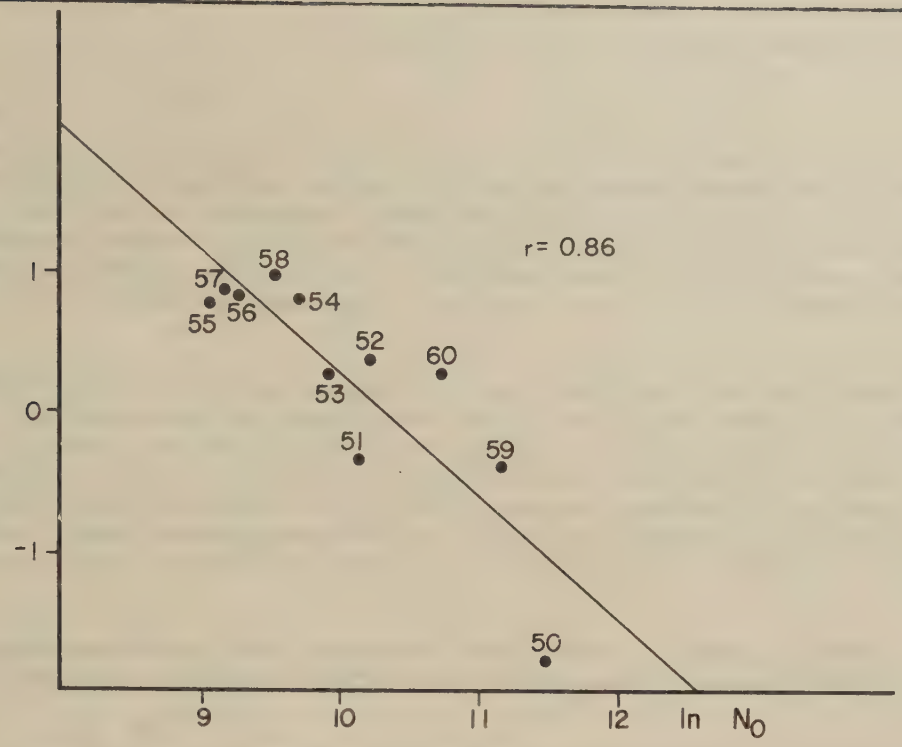


Fig.1 Natural logarithm of the sum of the fishing mortalities on 0- and 1- group herring (F_0+F_1) against natural logarithm of initial year-class size as 0-group (N_0) for the 1950-1960 year-classes.

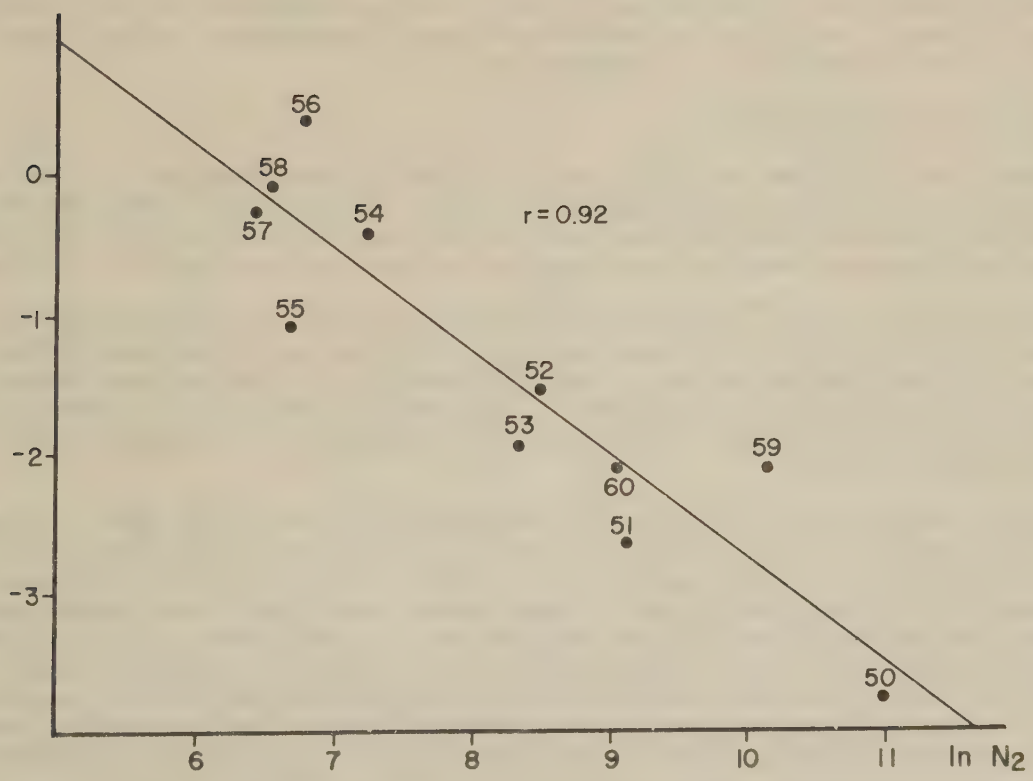


Fig.2 Natural logarithm of the fishing mortality on two-year-old herring (F_2) against natural logarithm of the number of two-year-old herring in the beginning of the year (N_2) for the 1950-1960 year-classes.

Equation (1) would then mean that q is proportional to N^{-b}, i.e.

$$q = k \cdot N^{-b} \qquad (2)$$

N in Figs.1-2 is the number present at the beginning of the year. If (2) gave the relationship between q and number present at any time during the year, an exponent b = 1 would mean that catch and catch per unit of effort were independent of stock size. b = 0 would mean that the usually assumed relationship (catch per unit of effort proportional to stock size) was valid, while $0 < b < 1$ would mean that there was some increase in catch per unit of effort with increasing stock size, the rate of increase decreasing with increasing b.

No firm conclusions can be drawn from Figs. 1-2 because no data on total effort are available. If there was a trend with time in the total amount of fishing effort in these fisheries during the period studied, this would affect the slope of the lines in Figs.1-2 if there was also a certain trend with time in year class strength. This is to some extent the case; the average size of the year classes 1950-1953 is higher than for year classes 1954-1958. In 1959 and 1960, however, two strong year classes appeared again, and this would tend to decrease the effect of a possible time trend in effort on the slope of the lines.

More or less random variations in effort not correlated with year class strength would mainly only increase the variation around the lines in Figs.1-2 and not significantly affect the slope.

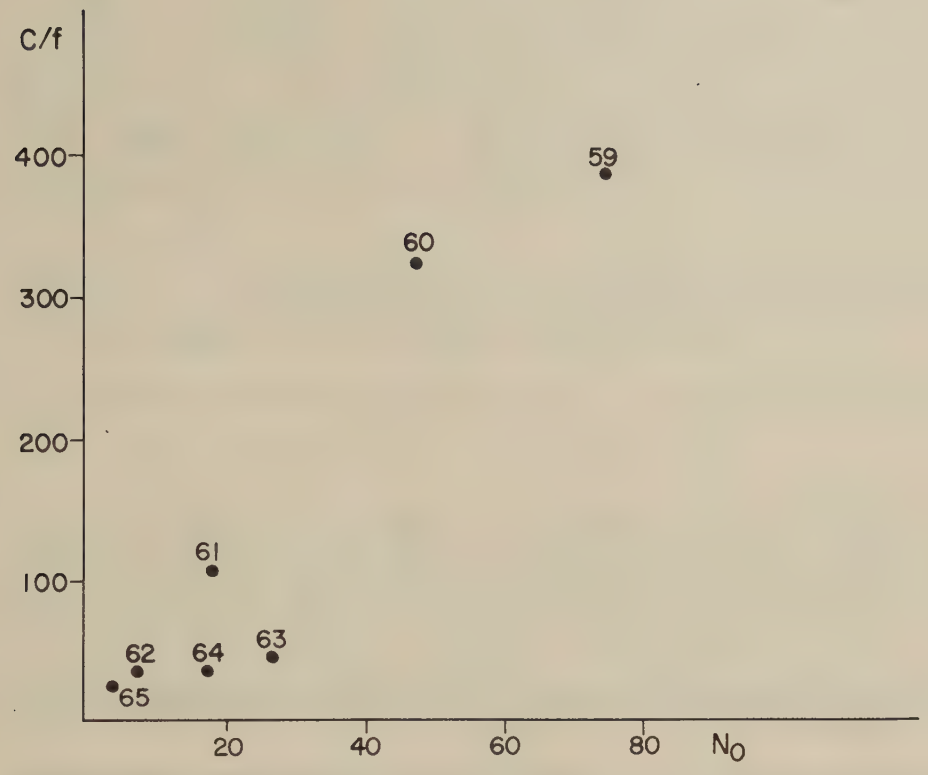
The analysis in Figs.1-2 was restricted to the year classes of 1950-1960 in order not to make the time period too long and thereby increase the chances for great changes in the effort. For the year classes 1959-1965 some catch per unit of effort data (catch per vessel per month) in the autumn fishery for 0- group herring in northern Norway are given by Dragesund (1970). In Fig.3 are plotted the catchability coefficient q and the catch per unit of effort resulting from his data against year class strength from cohort analysis. Fig.3 shows an increasing catch per unit of effort with increasing year class strength. No correlation between q and N can be demonstrated here, contradictory to what Figs.1-2 indicate, but the variation in q is appreciable.

3. THE FISHERY ON ADULT HERRING

Østvedt (1964) compared the catch per unit effort in the Norwegian gill-net and purse seine winter herring fishery in the period 1947-1960. He concluded that catch per unit effort for both gears followed the same trend as the total catch, but that the catch per unit of effort for purse seine showed a greater variability than that for gill-net.

Using Østvedt's figures (1964) for catch per unit effort and estimates of spawning stock size (in number) from cohort analysis, the catch per unit effort was plotted against stock size for both purse seine and gill-net (Figs.4-5). For the gill-net data a linear regression of C/f against N is significant at a 2 percent level (Fig.5) and the intercept on the C/f-axis is very near zero. For the purse seine data the regression is not significant at a 5 percent level.

Østvedt (1964) pointed out that the age-composition of the stock could influence the catch per unit effort in the purse seine fishery: "It is a well known experience of the fishing skippers that the bigger herring (i.e., older) are more difficult to catch than the younger ones. The bigger herring readily seek deeper water during the fishing operation and thus escape the net more often than the smaller ones. In the years with high catch per unit of effort (1954-1956), recruit spawners made up 30-40 percent of the catch, while after 1958 the number of recruit spawners has been reduced, constituting less than 15 percent of the catches". In order to analyse possible relationships between the catchability coefficient (q) and stock size (N) the author therefore decided not to use the data from 1954-1956.



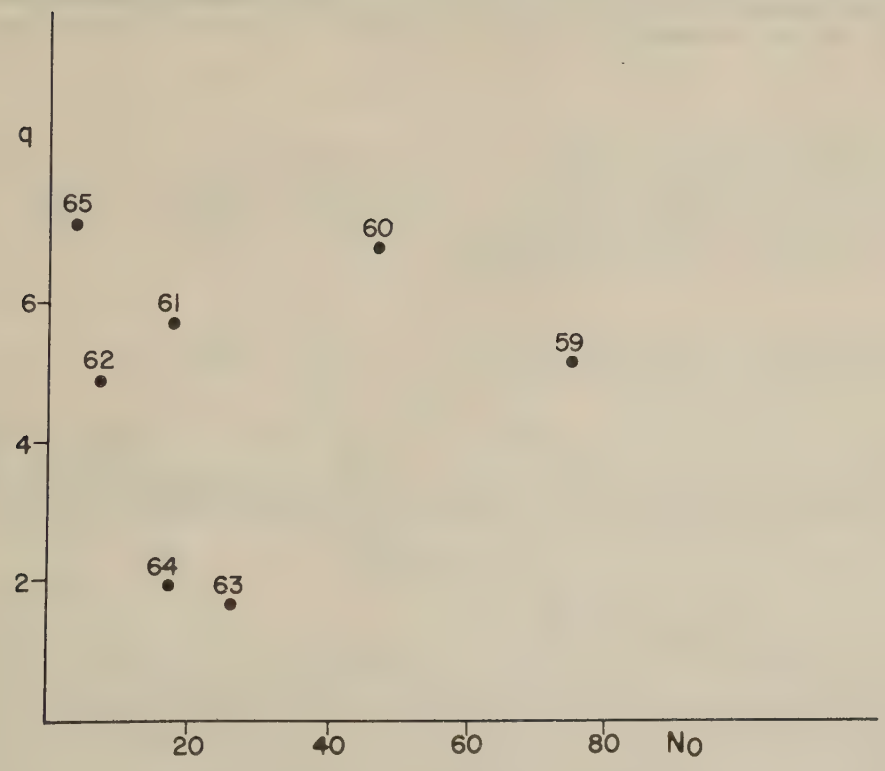


Fig.3 Catch per unit of effort (upper figure) and catchability coefficient (lower figure) during autumn fishery for 0-group herring in northern Norway against initial year-class size as 0-group for the 1959-1965 year-classes.

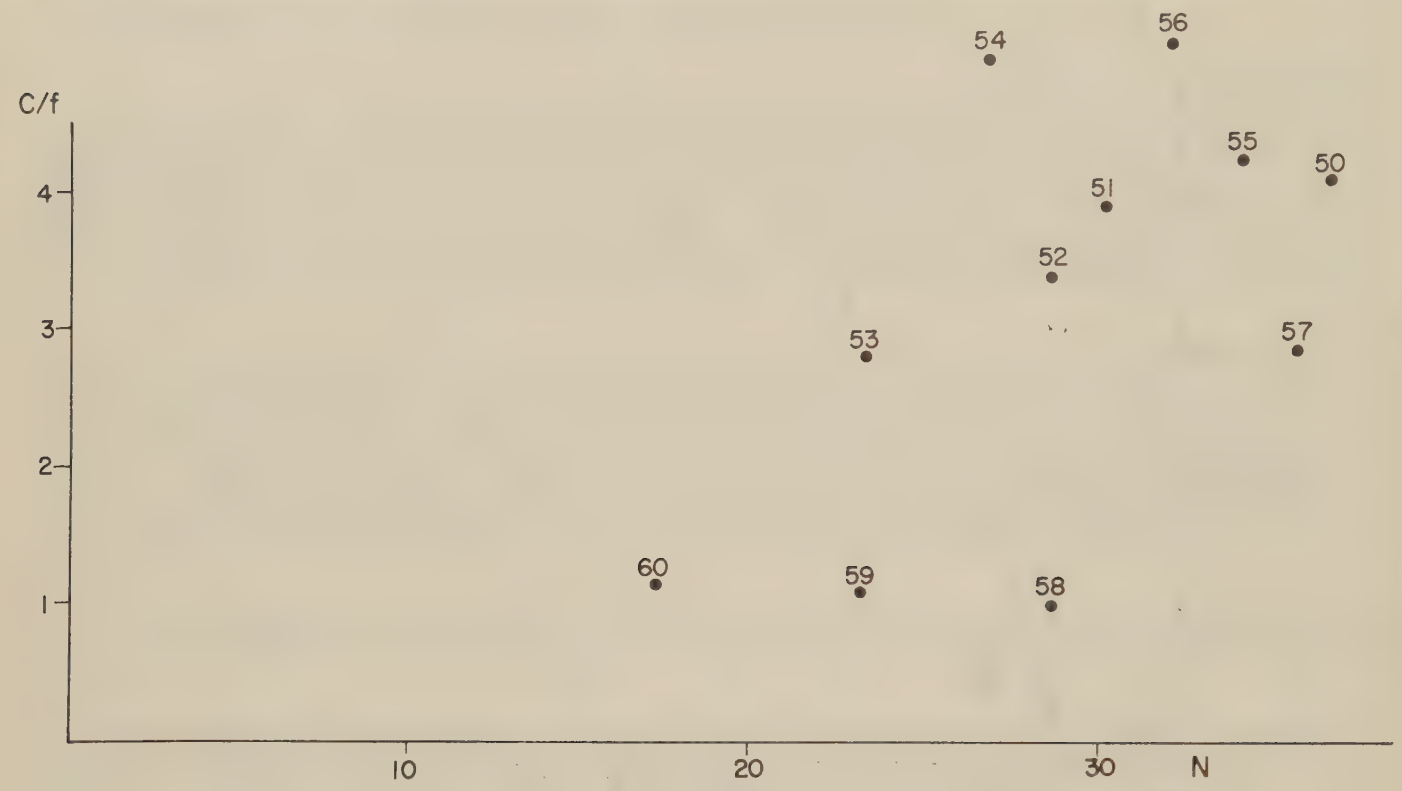


Fig.4 Catch per unit of effort in the Norwegian purse seine fishery for herring against stock size in numbers in the winter seasons 1950–1960. Effort measured as number of boats.

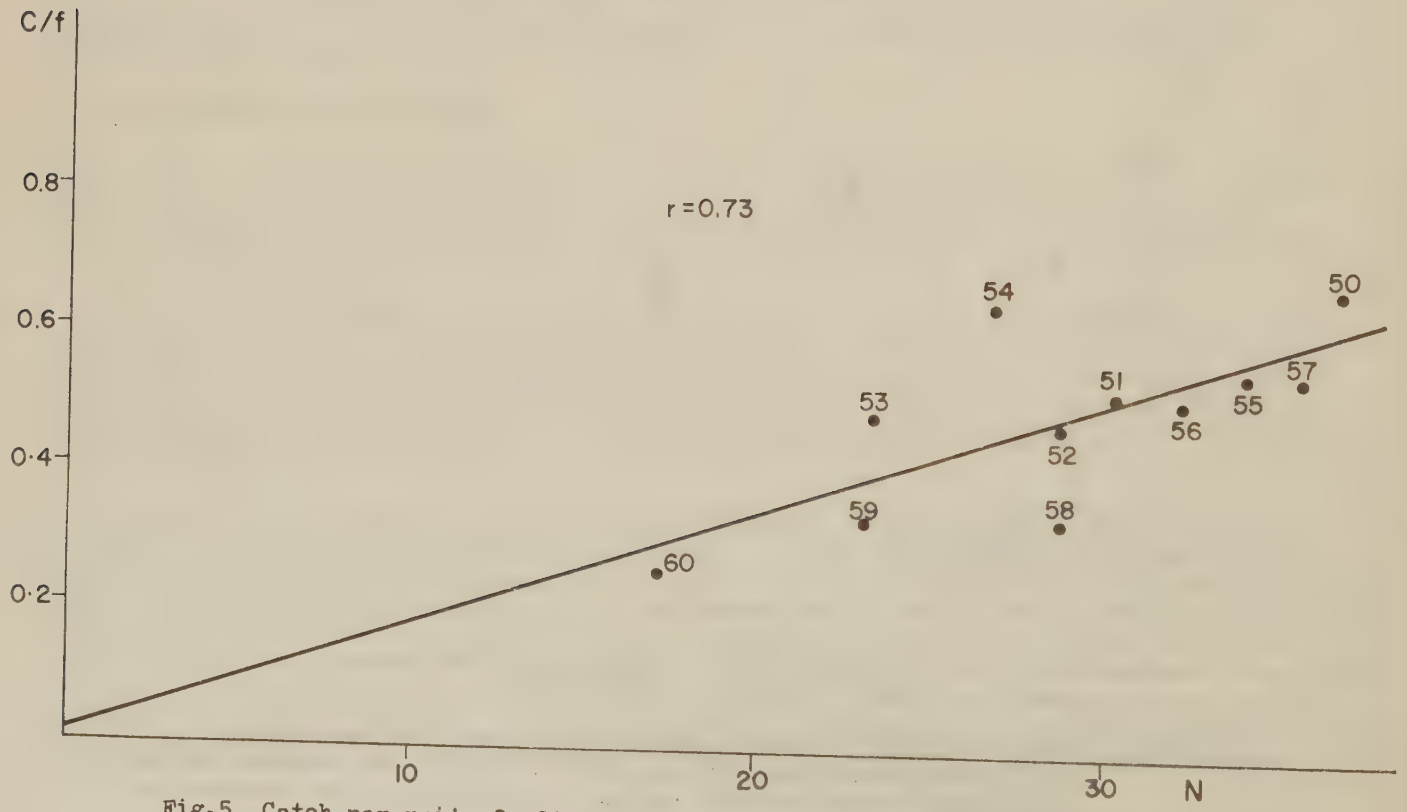


Fig.5 Catch per unit of effort in the Norwegian gill-net fishery for herring against stock size in numbers in the winter seasons 1950-1960.

Østvedt (1964) measured the effort in the gill-net fishery as (number of boats) x (days with catch), while for the purse seine fishery he measured it simply as number of boats. Whatever the relation between stock size and catchability coefficient (q) is, the fishing mortality (F) should increase with increasing effort (f) if the effort is measured in a meaningful way. To test whether this is the case for the purse seine fishery when f is measured as number of boats, the fishing mortality generated by the purse seine fishery was plotted against effort (Fig.6). The fishing mortality was calculated as the total fishing mortality on 7 year-old and older herring from cohort analysis in the different fisheries according to their catch in numbers.

Fig.6 clearly indicates a poor measure of fishing effort. If q varies with stock size, differences in stock size could of course completely disturb the picture. However, even among years with about the same stock size (1951-1952 and 1958, 1953 and 1959, 1950 and 1957) there seems to be no relation between f and F.

The alternative way to measure the effort from the available data in Østvedt (1964) is to put

$$f = (\text{number of boats}) \times (\text{days with catch})$$

as Østvedt in fact did for the gill-net fishery. The plot of fishing mortality against effort measured in this way is shown in Fig.7. Fig.7 shows at least a tendency of increasing F with increasing f, and it was therefore decided to use this measure of effort in the further considerations. Also the year 1950 had now to be deleted from the analysis because the number of days with catch are not given for this year.

In Fig.8 the catch per unit of effort is plotted against the new measure of effort. The figure indicates that there is still no correlation between the two variables.

In Fig.9 is given the plot of ln q against ln N. A linear regression of ln q on ln N is highly significant ($r = 0.9745$). The slope of the line is -1.375, giving the following relation between q and N:

$$q = a N^{-1.375} \qquad (\text{or } F = a \cdot f \cdot N^{-1.375}) \qquad (3)$$

Fig.10 shows the estimated relation (3) between q and N together with the observed points. The value of the exponent (-1.375) in the equation above, however, can hardly give the correct relation between q and N because a value of b greater than 1 implies that the catch per unit effort decreases with increasing stock size ($F = a \cdot f \cdot N^{-b}$ and

$$C = F \cdot \frac{N}{Z} \left(1 - 1^{-Z}\right) = F \cdot \bar{N}$$

implies that $C/f = kN^{1-b}$ if $\frac{\bar{N}}{N}$ is assumed approximately constant from year to year).
The slope in Fig.9 must therefore be too steep.

The conclusions from Figs.8-10 must be that q decreases with increasing stock size and that therefore no relation between catch per unit of effort and stock size can be demonstrated.

4. CONCLUSION

If the catchability coefficient q in a purse seine fishery increases with decreasing stock size as the data presented in this paper indicate, this has two important consequences. Firstly, catch per unit of effort data cannot give an index of abundance unless b in equation (2) is significantly less than 1 and its value is rather precisely known (it seems unrealistic to hope to get precise estimates of b because of the variance, and also bias, usually present in catch per unit of effort data). Secondly, a certain fishing effort will generate a steadily higher fishing mortality as stock size decreases, and this may rapidly

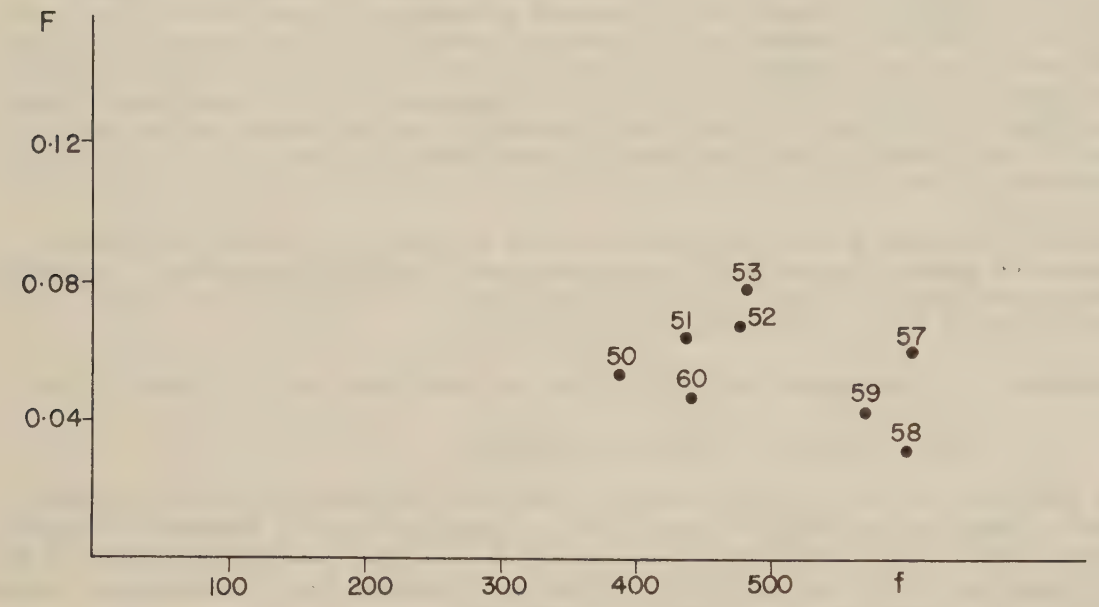


Fig.6 Fishing mortality generated by purse seine in the winter herring fishery against fishing effort measured as number of boats.

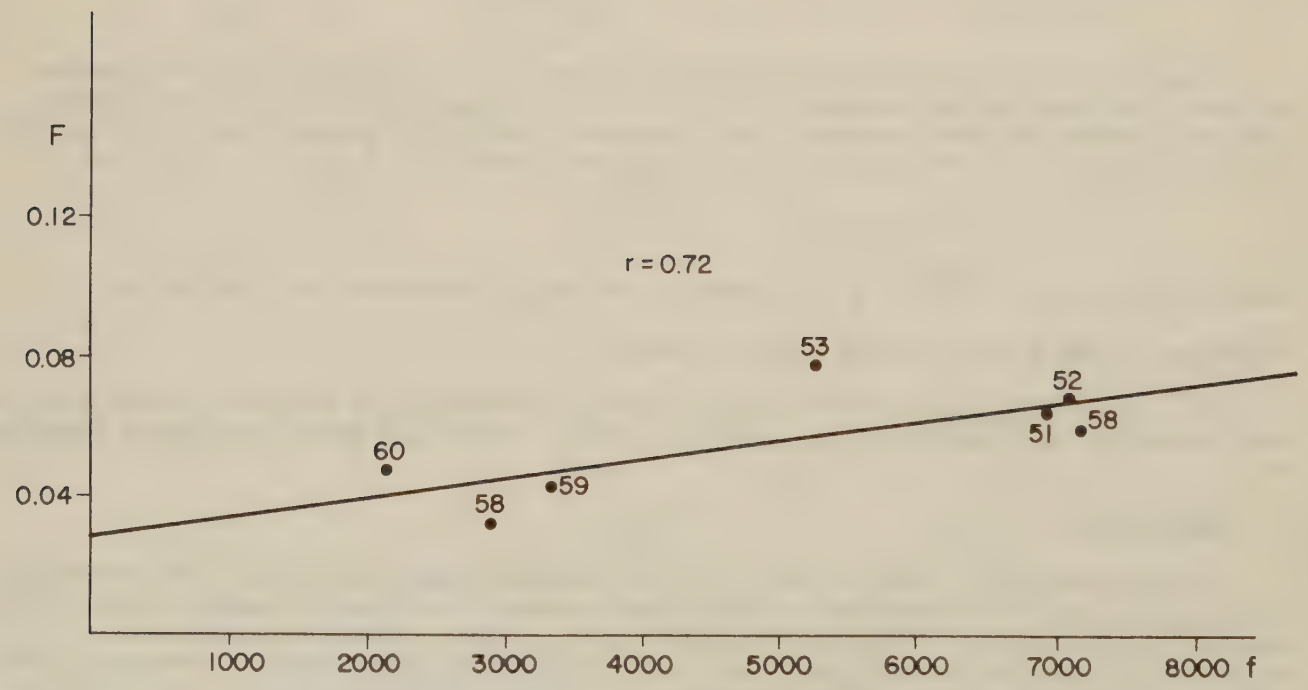


Fig.7 Fishing mortality generated by purse seine in the winter herring fishery against fishing effort measured as number of boats x days with catch.

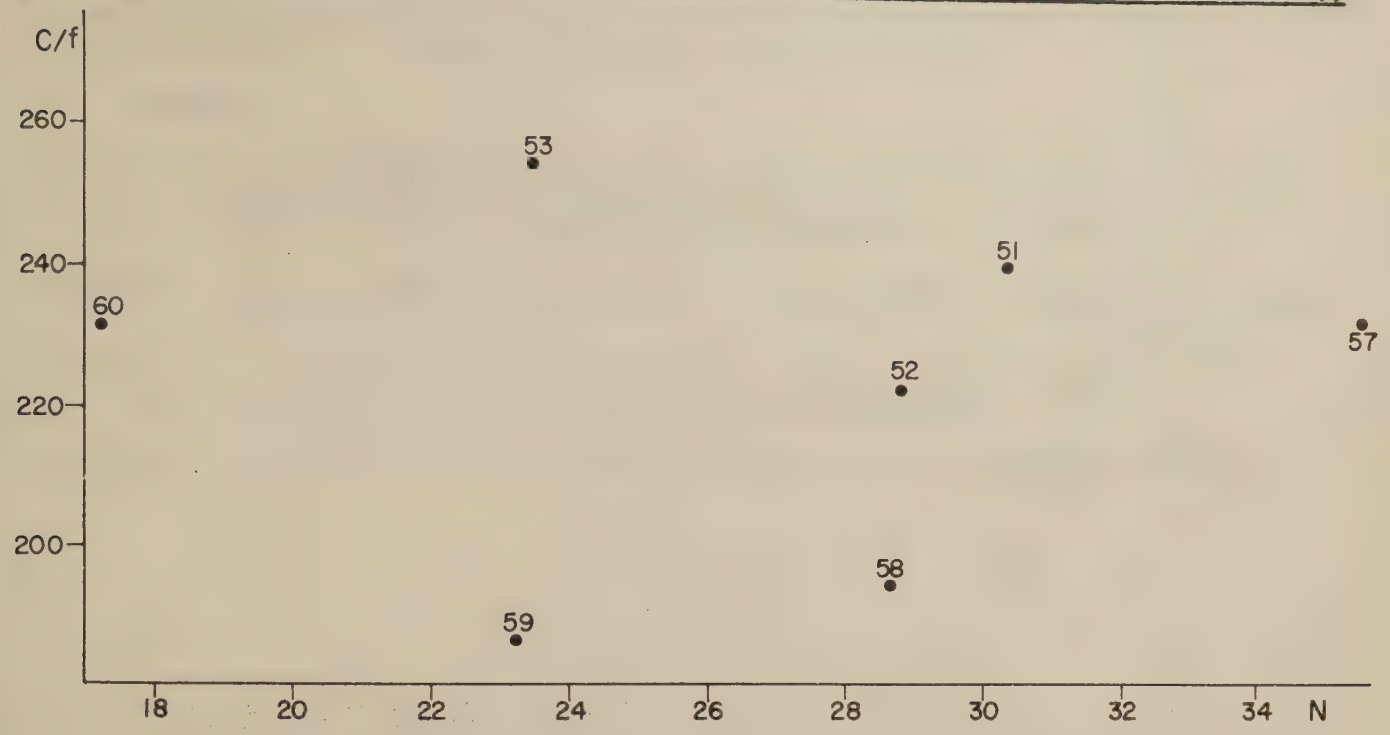


Fig.8 Catch per unit of effort by purse seine in the winter herring fishery against stock size. Effort measured as number of boats x days with catch.

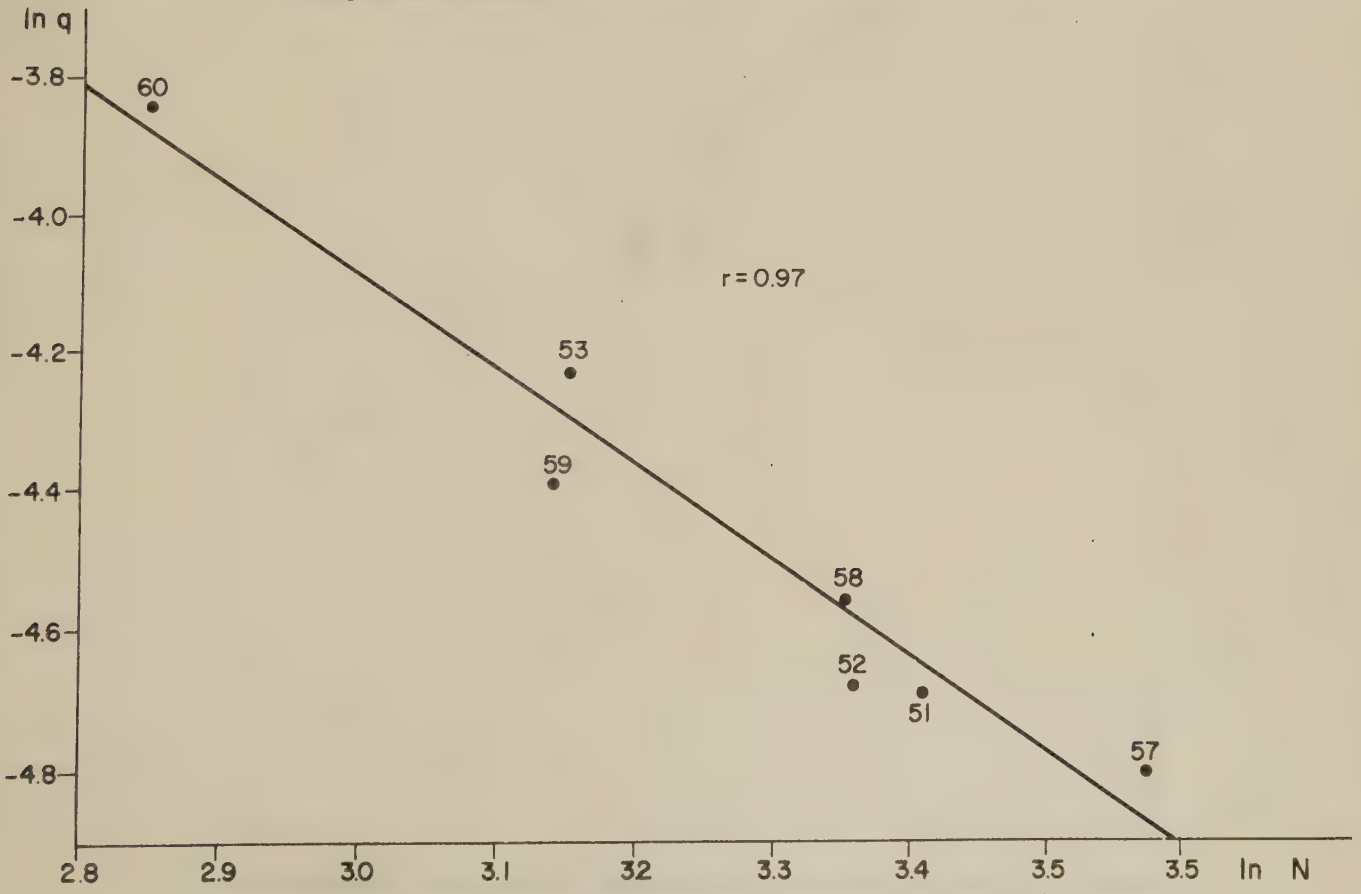


Fig.9 Natural logarithm of the catchability coefficient (q) in the winter herring fishery with purse seine against natural logarithm of stock size in numbers.

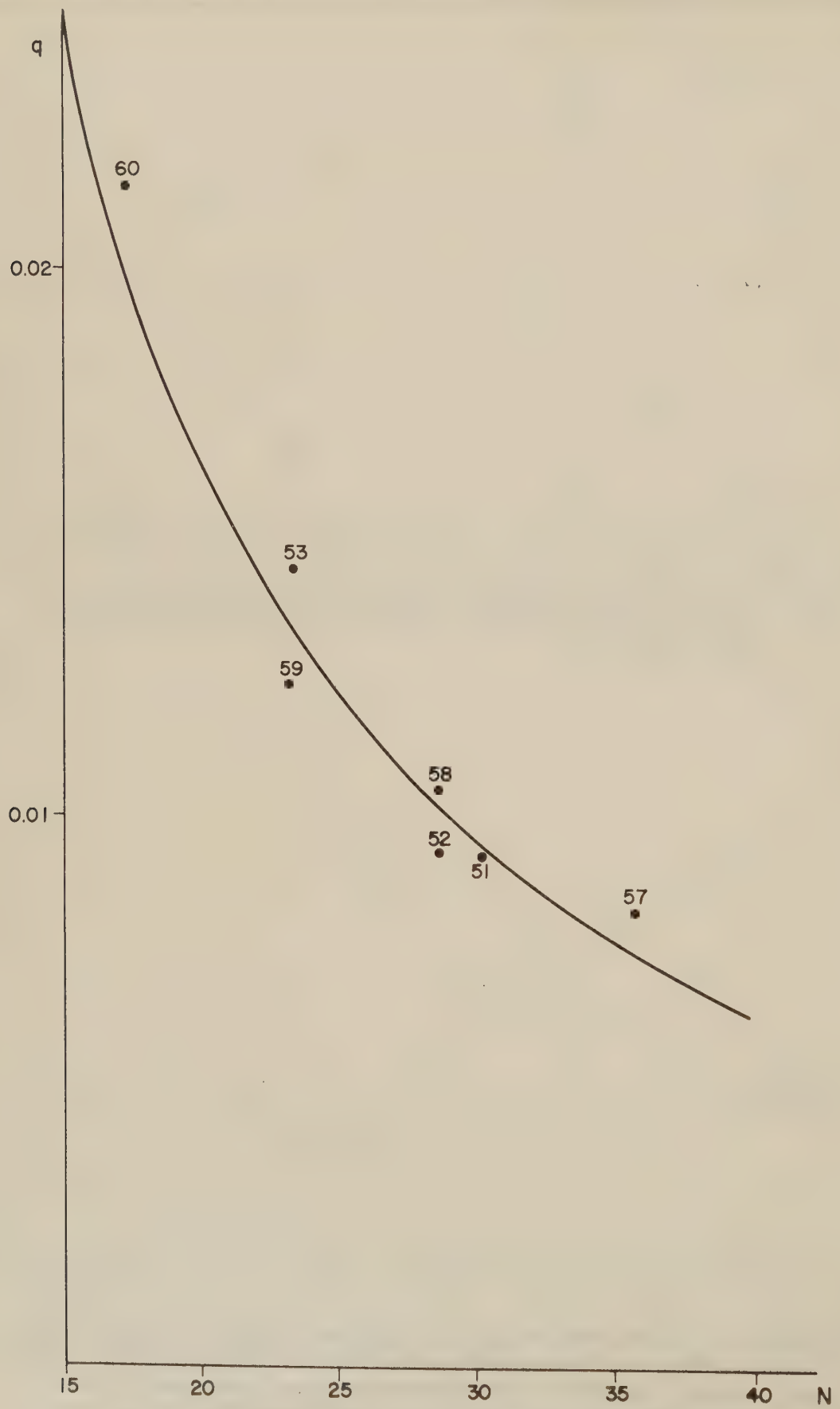


Fig. 10 The estimated relation between catchability coefficient (q) and stock size in the winter herring fishery with purse seine.

cause total collapse in the stock (as it did for the Norwegian spring spawning herring) if fishing mortality is not regulated directly through catch quotas.

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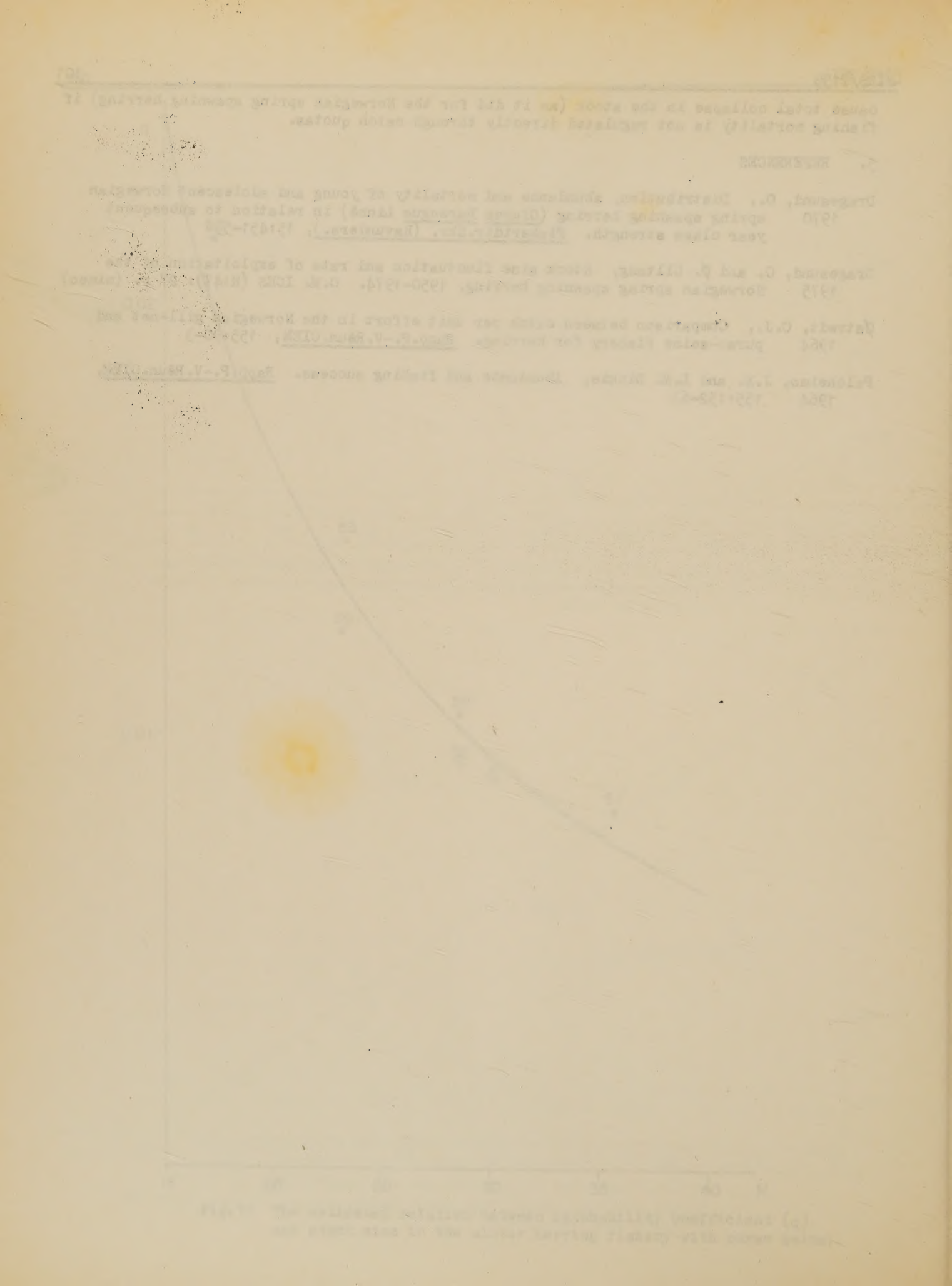

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